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BIOLOGICAL SCIENCES CURRICULUM STUDY

Yellow Version
BIOLOGICAL SCIENCE: AN INQUIRY INTO LIFE
Harcourt, Brace & World, Inc.

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HIGH SCHOOL BIOLOGY: BSCS GREEN VERSION
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(Other titles in preparation) D. C. Heath & Company

Biological Investigations for Secondary School Students: Research Problems in Biology for the Schools, Doubleday & Company, Inc.

MATERIALS FOR THE TEACHER
Biology Teachers' Handbook, John Wiley & Sons, Inc.
Innovations in Equipment and Techniques for The Biology Teaching Laboratory, D. C. Heath & Company

BSCS Pamphlet Series, D. C. Heath & Company

CURRICULUM STUDY BULLETINS:

Hurd, P. DeH. 1961. *Biological Education in American Secondary Schools, 1890–1960*. BSCS Curriculum Study Bulletin No. 1, American Institute of Biological Sciences, Washington, D.C.

Brandwein, P. F., J. Metzner, E. Morholt, A. Roe, W. Rosen. 1962. *Teaching High School Biology: A Guide to Working with Potential Biologists*. BSCS Curriculum Study Bulletin No. 2, American Institute of Biological Sciences, Washington, D.C.

BIOLOGICAL SCIENCES CURRICULUM STUDY

Initiated by the AMERICAN INSTITUTE OF BIOLOGICAL SCIENCES

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TEACHER'S MANUAL

BIOLOGICAL SCIENCE

AN INQUIRY INTO LIFE

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ABOUT THE INDIAN EDITION

The Biological Sciences Curriculum Study comprises a group of American biologists who are interested in improving the teaching of biology in the high schools in the United States. In order to contribute to such an improvement the BSCS has prepared, with financial support from the U. S. National Science Foundation, a variety of printed materials of which *Biological Sciences : An Inquiry Into Life* is one example.

This version (consisting of a textbook, laboratory manual and a teacher's guide) was designed for American students. The high school teachers and college professors, who were the writers, had the domestic educational pattern in mind and placed primary emphasis on the North American fauna and flora.

It follows that we do not feel that the BSCS materials are appropriate for use in the classrooms of other nations without specific modification for the local biota, customs and educational systems. We do hope that Indian colleagues will prepare such an adaptation and we would feel privileged to work with them towards such a goal.

For the interim, the National Council of Educational Research and Training have suggested to us that it would be useful to have our books reprinted in India in a limited edition so that they could be generally available to Indian scholars and teachers. Thus, interested persons could review them while weighing the advantages and disadvantages of an adaptation. We were delighted with this suggestion by the NCERT and have been pleased to do what was necessary to make this possible.

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CONTENTS

INTRODUCTION

Evolving education, as evolving life, is a process of adaptation to change. Nowhere is change more rapid and continuing than in the sciences, and nowhere in the sciences are advances being made more rapidly than in biology.

Just as biological evolution tests the mettle of organisms, so does educational evolution place adaptive stress upon us as teachers. Out of this stress grows understanding—and an adaptation to evolving curricula. To facilitate for busy teachers the requisite understanding and use of new curricular materials, this manual for the textbook BIOLOGICAL SCIENCE: AN INQUIRY INTO LIFE was created.

For each chapter in the textbook, a teacher's rationale has been provided in this manual. The rationale brings into focus the critical ideas of the chapter, and also serves to identify the chapter in relation to other chapters and to the general pattern of the entire course. From a collective reading of the rationales it is hoped that the teacher's appreciation of the pattern, organization, and emphasis of the textbook will be reinforced and that classroom activities can better be directed in a purposeful and integrated fashion.

Following the rationale for each chapter are answers to the end-of-chapter questions. In the textbook, the questions are listed roughly in order of increasing difficulty, from the relatively simple to the more demanding; teachers can thus assign the questions to students according to a selective estimate of student abilities. The answers as given in this manual are not intended as models for student responses, but rather as indicators on which to base classroom discussions of the adequacy of student responses.

The bibliographical references that follow the answer section for each chapter are selected for modernity, accuracy, and variety in depth of coverage. Some of the books listed are elementary, others quite specialized and advanced. Thus, the teacher has a selection from which to pick appropriate books for interested students of varying abilities.

A broad variety of films is listed for each chapter, to provide an audio-visual selection from which the teacher may choose, for preview and class use, whatever films are thought necessary.

If this manual serves to facilitate the classroom use of BIOLOGICAL SCIENCE: AN INQUIRY INTO LIFE, the effort spent in preparation of these materials will have been most amply repaid. While fully recognizing the debt to others for their contributions, the undersigned assumes responsibility for any errors of omission or commission. Teacher comment for incorporation into future editions of this manual will be gratefully acknowledged.

William V. Mayer
Wayne State University

December 3, 1963

PART I
UNITY

Chapter 1 BIOLOGY— WHAT IS IT ABOUT?

RATIONALE

To introduce students to biology, Chapter 1 briefly presents three different perspectives of the structure of this vast science. First is a glimpse of biology in terms of the arbitrary (but necessary) division of the whole into a number of major areas of study. Second is another glimpse in terms of the basic patterns or themes in life that relate every organism to every other one. Third is the history of a biological problem, one from among hundreds of thousands, reconstructed to suggest how biological knowledge is gained where little or none was known before.

All that biology is cannot be introduced in one chapter; the entire high school course is devoted to this purpose. It is appropriate to caution that Chapter 1 is not intended as text for elaborate study and discussion (which from the student's point of view could only be based upon inadequate knowledge).

What Chapter 1 first mentions will recur again and again, each time more meaningfully, as students proceed with their reading and with their laboratory investigations. One partial exception is the case history of a biological problem: its subject matter, malaria, the world's major disease of man, will not be treated elsewhere—but the topic of biological problems (whatever they may concern) will be treated continuously. Malaria and the history of man's concern with it serve here to introduce students to such terms and ideas as hypothesis, deduction, experiment, data, and some of the ways in which these are used to reach a verifiable conclusion—that is, knowledge.

The usefulness of Chapter 1, as it briefly has been analyzed here, fits well with the recognition that the first days of class are unusually busy. The chapter can be assigned largely (or entirely) as the homework assignment for the first few days.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 22)

1. a. Morphology is the science of structure of living things.
   b. Physiology is the science of function of living things.
   c. Function cannot be understood without a knowledge of the structures

involved. Similarly, structure cannot be fully appreciated without a comprehension of the function the structure performs.

   d. Complementarity of structure and function.

2. a. Ecology is the science of the behavior of whole organisms and groups of organisms in relation to their total living and nonliving environments.
   b. Relative abundance or scarcity of water is the major determining factor to which the various plants have been adapted in the different environments.
   c. The complementarity of organism and environment.
3. Discard or modify the hypothesis; or design additional experiments; or reformulate the hypothesis in relation to the new experimental data.
4. On the basis of the data, it is a reasonable prediction. However, just as man has known how to wipe out such diseases as smallpox and syphilis but has failed to do so, it seems likely that he may not in the near future eliminate or control malaria on a worldwide basis.
5. Chills and fever are experienced when the parasites burst from the red blood cells of the victim. As this point in the life cycle of the parasites takes place at definite intervals of time, the type of malaria can be diagnosed by measuring intervals between attacks of chills and fever.
6. No. No arrangements had been made to eliminate all other possible causes of malaria. Many examples of the presumed phenomenon would have been necessary before the evidence might have been considered conclusive.
7. Their remains have been preserved in the rocks as fossils.
8. Yes, in the sense that the splint bones have no present use. However, they are remnants of structures that did have a use in earlier relatives of the horse; thus, the idea that structure implies function is <u>not</u> refuted categorically.
9. a. Deep, relatively soft, moist soil; or, arid areas of infrequent rains and low water tables.
   b. Very wet soil.
   c. A swampy or boggy area.
   d. A pond, stream, or lake area; also, a meadow or woods with standing pools of water.
   e. A desert or area of low rainfall.
10. <u>Data</u> are the results of observations and experiments; they help lead to new hypotheses and to new data resulting from further experiments. A <u>hypothesis</u> is a belief to be tested. A <u>deduction</u> is a logical consequence of a hypothesis; deductions from a hypothesis provide specific ways in which the hypothesis can be tested. An <u>experiment</u> is a practical test of a hypothesis, or of deductions from it. <u>Confirmation</u> is verification of experimental results, data, or hypotheses. <u>Equipment</u> is that apparatus necessary to perform an experiment or make an observation; for example, the microscope was an essential piece of equipment for the discovery of *Plasmodium*.
11. Marshes, *Anopheles*, and *Plasmodium* are all related. The *Plasmodium* requires the mosquito as vector and the mosquito requires the marsh for breeding. The rupture of red blood cells by the *Plasmodium* is not a cause of the disease but a symptom of it. (This question can serve as a basis for developing an interesting discussion of "cause.")

REFERENCES

Chapter 3 of the BSCS *Teachers' Handbook** elaborates on the major biological themes and contains a discussion of the use of the term "theory." Chapter 4 of the *Teachers' Handbook* introduces teaching through "Invitations to Enquiry," which will be cited frequently in subsequent course work; Invitation No. 10, which may be used with Chapter 1 of the textbook, is concerned with the relationships of environment and disease, and with the phenomena of hypothesis and experiment.

The following issues of *Scientific American* will be found of value for the topics named:

Malaria—June 1952, page 22; May 1962, page 86.
Mosquitoes as Disease Vectors—September 1949, page 18; June 1952, page 22; October 1952, page 21; February 1954, page 30

FILMS

Cell Biology, Part I: *The World of Life*, No. 1, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 2 LIFE FROM LIFE

RATIONALE

At the beginning of Chapter 2, students are asked, "What is life?" This is the ultimate question of all biology, and the students are led to understand that their definitions are inadequate, that life is almost impossible to define. The question is redirected toward the origin of living things, and the remainder of the chapter focuses upon one aspect of this origin—the source of organisms that appear in rain puddles, refilled ponds, hay or yeast infusions, and wherever else life is observed where none was believed to exist before. Chapter 2 thus reconstructs the biogenesis-abiogenesis controversy.

Students will no more be able to give a complete definition of life at the end of this chapter than they could at the beginning. However, they will have thoroughly established the concept of all life from life. A description (not a definition) of life that will be satisfactory can await student experience with further topics in the text and with organisms in the laboratory.

This chapter again approaches biology historically—through the search for answers to biological problems initially raised long ago. Biological thought beginning with the reflective, only rarely partly experimental approaches of Aristotle and of van Helmont is reviewed, and the experimental method made famous by Redi, leading to confirmation of results, is introduced. The pattern from observation to hypothesis to deduction to experiment to conclusion is exemplified by the work of Redi, Joblot, and Pasteur. All these examples should reinforce the students' understanding of the scientific process introduced in Chapter 1. The discrediting by Pasteur of the hypothesis of abiogenesis is the capstone of this chapter's use of experimental method.

**Biology Teachers' Handbook*, Biological Sciences Curriculum Study, published by John Wiley & Sons, New York, 1963

The concluding admission that spontaneous generation is still an accepted hypothesis must be interpreted in light of an entirely new set of facts unknown at the time of the argument traced from Aristotle to Pasteur. This theory of the origin of life will be taken up in greater detail later (Chapter 36).

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 43)

1. Most plants and many animals (sponges, for example) do not move about, in the usual sense of the word. Seeds, eggs, and similar living objects also do not move. On the other hand, many nonliving mechanisms and objects—trains, planes, automobiles, rivers, planets, etc.—do move.
2. Accurate observations revealed no evidence for the hypothesis that geese develop from worms. Instead, careful observation and study revealed the true nature of the reproduction of ship worms, goose barnacles, and barnacle geese, each animal after its own kind.
3. The experiment of placing three dead snakes in a box, watching them become covered with small maggots, and watching the maggots change to pupae and hatch into flies led Redi to his hypothesis that maggots are the offspring of flies and are not derived from the decay of meat.
4. The justifiable conclusion was that under the conditions of his experiments, maggots did not arise spontaneously in decaying meat; they appeared only if flies were allowed to lay eggs on the meat.
5. Redi observed the growth of insect galls on trees, but because he did not see the females lay the eggs that led to the formation of the galls, he believed that insects produced in the galls arose by spontaneous generation from plant juices. (See Figure 2-5, text page 32.)
6. Biologists had already discarded the idea of spontaneous generation of large animals, but the discovery of the microscope and of microorganisms led to the revival of the theory for microscopic forms.
7. A control in an experiment is a parallel experiment run with all conditions identical to those of the test experiment except for the one variable being tested. Joblot's control was open to the air; the experimental vessel was closed. All other conditions were identical.
8. Spallanzani obtained no evidence for spontaneous generation when he repeated Needham's experiments, <u>using air-tight seals</u> (in place of the corks used by Needham).
9. Pasteur's preliminary experiments of 1860, in which he opened flasks in the relatively "pure" air high in the French Alps, served to verify his hypothesis when only one of twenty flasks became contaminated with microorganisms.
10. Pasteur's use of 60 flasks demonstrated the relative concentrations of microorganisms in the air inside the building and outside, and related these factors to the appearance of microorganisms in the flasks. Four flasks that were swan-necked verified that air alone, without the spores of microorganisms, did not lead to the generation of microorganisms in the yeast infusions within the flasks. In brief, under the conditions of Pasteur's demonstration, spontaneous generation was shown <u>not</u> to take place.
11. Redi and Pasteur did not disprove spontaneous generation, but they did demonstrate that under the conditions of their experiments, spontaneous generation invariably did not occur. At the same time

they demonstrated that many so-called examples of spontaneous generation were not, and could be explained more scientifically as examples of reproduction.

12. Only by performing every conceivable experiment could spontaneous generation be entirely disproved. As this is manifestly impossible, spontaneous generation will never be disproved entirely. However, the experiments of Redi and Pasteur were so convincing and complete that there has been no serious question about reviewing the classical interpretation of spontaneous generation; thus, there has been no necessity to continue experimentation along these lines.

REFERENCES

Invitations 6 and 7 from the "Invitations to Enquiry" in the *Teachers' Handbook* (see footnote, page three of this *Teacher's Manual*) may be used either here, in relation to the planning and control of experiments, or later with Chapter 4 of the text.

Useful books:

Dubois, Rene. 1960. *Pasteur and Modern Science*. Doubleday Anchor Books, New York (Wesleyan University Press, Columbia 16, Ohio, handles distribution for secondary school students and teachers.)

Lindsay, Jean. 1959. *A Short History of Science*. Doubleday Anchor Books, New York (VI: "The Development of Scientific Instruments," and XI: "Pasteur and the Problems Presented by Bacteria.")

Nordenskiold, E. 1960. *The History of Biology*. Tudor, New York.

Sarton, G. 1952. *The History of Science*. Harvard University Press, Cambridge (Mass.)

Wightman, W. P. D. 1951. *The Growth of Scientific Ideas*. Yale University Press, New Haven (Conn.) (Part 2 deals with nature and life.)

FILMS

Continuity of Life: *The Characteristics of Plants and Animals*, 1954, (sd, b&w or c, 10 min), p or r, Indiana

Patterns of Life: *Living or Non-Living*, 1959, (sd, b&w, 29 min), p or r, Indiana

Microbiology, Part II: *The Very Small*, No. 1, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 3 BASIC STRUCTURE

RATIONALE

The primary purpose of Chapter 3 is to enable students to develop an awareness of the unity of structure in plants and animals. From their introduction to basic structure in this chapter, they will be led to an understanding of basic functions in Chapters 4, 5, 6, and 7 (and to an increasing understanding of basic structure).

The concept of unity of structural organization is developed through the historical emergence of the cell theory. Students are led through the discovery of cells, the elaboration of cellular structure in terms of cell walls, the critical redefinition by Schwann in terms of cell contents rather than cell walls (permitting recognition of cells in animals as well as in plants), and Virchow's lasting contribution explaining the origin of cells by division of other cells. (Students could well be asked how Virchow's observations must have contributed to the downfall of the hypothesis of spontaneous generation.)

Once again, as in Chapters 1 and 2, the methods of biological investigation are carefully recorded. It is not so much the cell theory as known today, but rather how it came to be, that receives the emphasis. Afterward, students are acquainted with some of the structures within plant and animal cells—structures common to both types, and other structures found in one type of cell but not the other. The nuclear phenomenon of mitosis, followed by cell division, is also introduced. However, neither cellular details nor the features of mitosis should be dealt with in detail here; they will be treated further in Chapters 6 and 7.

Chapter 3 does another thing. It distinguishes clearly between data-gathering, or observations *per se* (such as those of Hooke), and the organization of these observations into a meaningful pattern or broad biological generalization (such as the hypothesis that became the cell theory). The difference between basic science and applied technological science is also discussed; students are brought to a realization that neither exists without the other, and that both are essential for the progress of science and the increasing benefit of mankind.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 64)

1. The major problems were food and protection. Early man required food in order to live. As a hunter of animals and a gatherer of fruits, seeds, roots, and berries, he needed to know not only the different kinds of animals and their habits, but the different kinds of plants and whether they were edible. He also needed to protect himself from dangerous animals, especially the larger carnivores (which, like himself, required food in order to live).
2. Parts of wild plants were used for food, shelter, medicine, tools, and other similar purposes.
3. By knowing the buffalo, its anatomy, its "herd instincts," and where and when it generally could be found, the Plains Indians were able to stampede and slaughter it wholesale and use it as their main source of food, clothing, shelter, boats, cooking vessels, tools, toys, glue, and fuel.
4. Science is all organized knowledge of natural phenomena, together with the ways in which this knowledge is sought and gained. Technology is the exploitation of selected knowledge for material benefit; as such, it is usually based upon the organized knowledge of science. Because of the necessity for practical application of knowledge, technology existed before pure science did, and was the forerunner of science. Only recently in man's history have science and technology diverged; even today, the distinction between the two is not always easily demonstrable.

5. Probably not. The highly impractical and abstract discovery of "pure science" today may become a basic and important part of the technology of tomorrow.
6. A compound microscope would be less useful to a chemist, since it could not reveal to him the molecular or atomic structure of the substances with which he works. The biologist, on the other hand, while he, too, is interested in chemistry (the chemistry of living things), deals more often with materials whose activity is associated with highly organized structures visible under the microscope.
7. Hooke discovered and named "cells" and used his discovery of them to explain the properties of cork.
8. Insofar as Hooke made organized observations about the cellular structure of cork and used these observations to explain the known properties of cork, his observations do come under the heading of "science." They were not broad enough to be called science itself, however.
9. The first scientific societies and their publications developed interest in science by providing a means for those interested in science to meet, exchange observations, and discuss their problems and questions. Such interchange often was responsible for experimental ideas that led to later discoveries of major importance.
10. Schwann extended the concept of the cell to animals by emphasizing the importance of the nucleus and its surrounding cytoplasm, rather than the presence of a thick cell wall as in plants.
11. Schwann defined a cell as a structure with a nucleus, some surrounding substance, and some sort of a wall or membrane.
12. Schwann believed new cells were formed spontaneously, but Virchow maintained that all cells came from pre-existing cells.
13. The chemicals used to treat cells can create artifacts that may appear to be normal cell inclusions. These observations can be checked, however, either by looking at living cells or by utilizing many different staining and cellular preparation techniques.
14. A nucleus, nucleoli, chromosomes, a nuclear membrane, cytoplasm, mitochondria, Golgi bodies, ribosomes, and a cell membrane.
15. Mitochondria are important in making energy available to the cell. The chromosomes control all activities of the cell and contain the code that carries the hereditary instructions for perpetuation of the individual race of organisms. Chloroplasts contain chlorophyll, necessary for photosynthesis.

REFERENCES

Invitations 1 and 2 from the "Invitations to Enquiry" in the *Teachers' Handbook* deal with the cell and its nucleus and should be used in classroom discussions at this point.

Useful books:

Newman, J. R. (ed.), 1955. *What is Science?* Simon and Schuster, New York

Porter, E., and M. A. Bonneville. 1963. *An Introduction to the Fine Structure of Cells and Tissues.* Lea and Febiger, Philadelphia

Toulmin, S. 1960. *The Philosophy of Science.* Harper Torchbooks, New York

Articles in journals:

Baserga, R., and W. E. Kisieleski. 1963. "Autobiographies of Cells." *Sci. Am.* 209 [2] 103

DaC. Andrade, E. N. 1954. "Robert Hooke." *Sci. Am.* 191 [6] 94

Schwab, J. J. 1960. "What Do Scientists Do?" *Behavioral Science*, 5 [1]

FILMS

Cell Biology, Part I: *The Unit of Life*, No. 2, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

The Cell—Structural Unit of Life, 1949, (sd, b&w or c, 11 min), p or r, Coronet

Chapter 4 BASIC FUNCTIONS

RATIONALE

The basic idea of this chapter is the firm establishment of the fact that biological function is explicable in terms of the laws of chemistry and physics—the same laws, essentially, that apply to nonliving materials of the earth.

Again, in this chapter, students return to the question, "What is life?" By now they have learned that life involves the ability to reproduce, and that in reproduction, like comes from like. A basic structural similarity—the cell—has been established, as have numerous structural similarities within cells. Now the vitalist-mechanist argument is used as an introduction to the chemistry, and in part the physics, of life processes. The historical approach continues to use the terms and ideas of hypothesis, deduction, theory, and other characteristic features of scientific methodology.

One of the most difficult problems of biology teaching—and one that can no longer be bypassed or ignored—is winning students to chemistry, and in part physics, and how they contribute to understanding living organisms. In preliminary editions of the textbook, thousands of feedback reports from teachers and students indicated the difficulties then being encountered with the original two chapters of manuscript. Now there are three—Chapters 4, 5, and 6—and the first of these offers an easy approach to living chemistry. Without formulae, but with implicit answers to the question, "Why chemistry in a biology course?" Chapter 4 leads historically from the first discoveries of similarities between organisms and inorganic chemical reactions to the point at which biologists first realized that life is chemical in its nature.

While not disproving the theory of vitalism, the conclusion is inescapably that physiological problems are approachable by the methods of chemistry and physics—that, in fact, they cannot be understood without resort to chemistry and physics. Students are thus "primed" by the easy approach of Chapter 4 for the understanding they must seek by way of chemistry in Chapters 5 and 6.

1. Because the mechanist assumes that life can be explained entirely in chemical and physical terms, his assumptions and hypotheses are subject to verification by experiment. The vitalist, however, assumes that life is made possible by a special force; he cannot verify his assumptions because the special force is not subject to experiment.
2. Van Helmont thought that the water was converted into the living substance of the willow tree. If he had known that water was merely a compound of hydrogen and oxygen, and that carbon, nitrogen and a great number of other elements made up the substance of the tree, he would have known that his conclusion was incomplete. Water alone could not have provided all these elements.
3. The phlogiston theory assumed that after a substance burned, its remains would be lighter in weight (because the "phlogiston" it contained would have burned off). However, with the advent of scales and balances it was found, in the case of burning such substances as copper, that the weight actually increased, which cast severe doubt on the validity of the phlogiston theory.
4. Experiment showed that the gain in weight of the burned material (phosphorus) was exactly equal to the loss in weight of the surrounding air, and, moreover, that only 1/5 of the air (by volume) appeared to be usable in this process. Lavoisier postulated that air consisted of two parts or gases, one that will combine with burning phosphorus and another that will not.
5. Observations indicated that the gas given off by fermentation was carbon dioxide, which would support neither burning nor respiration. Priestley's investigations of carbon dioxide led eventually to his discovery of oxygen and its relationship to photosynthesis.
6. Among other things, Priestley liberated oxygen from red oxide of mercury. Lavoisier related this finding to his own work with the combustion of phosphorus, then guessed the relationship that led to his completion of the cycle shown in Figure 4-8, page 78.
7. Use of the chemical balance showed that the ratio of different elements in a compound always was the same. The fact that the elements in a compound occur in constant proportion by weight led Dalton to the formulation of the atomic theory.
8. a. Matter is composed of particles that are indestructible, indivisible, and discrete.
   b. All atoms of a single element are alike.
   c. The atoms of different elements differ from one another.
   d. Compounds are formed by the union of atoms, and only whole atoms can combine.
9. Prior to the time of Wöhler, it was believed that inorganic and organic compounds were separate and unrelated. Wöhler's synthesis of an organic compound indicated that this was not so. Wöhler's synthesis of urea, however, was accomplished with materials of organic source. One of his students, Kolbe, performed the first synthesis of an organic compound solely from inorganic materials.
10. Oxidation in both nonliving and living substances requires oxygen, produces heat, involves the conservation of mass, gives off carbon dioxide, and produces water. In the case of fire, the oxidation is rapid, but in the case of rust, the oxidation is slow. Oxidation in living

systems takes place at a controlled rate and is used as a carefully regulated energy-release mechanism; often there is an associated mechanism for oxygen distribution and for maintaining a certain level of oxygen supply.

11. The specific chemical nature of diastase was established by its extraction from barley seeds, filtration, and precipitation with alcohol.
12. The discoveries from the seventeenth to the end of the nineteenth century showed there was no basic activity of life that could not at least be considered by use of the methods of chemistry and physics. Every biological problem was approachable by the laboratory scientist and it was not necessary to invoke a vital force to explain the data of the physiology of cells and organisms.

REFERENCES

Useful books:

Bertalanffy, L., von. 1960. *Problems of Life*. Harper Torchbooks, New York

A lucid account of vitalism and mechanism is included.

Burtt, E. A. 1954. *Metaphysical Foundations of Modern Science*. Doubleday Anchor Books, New York

Danto, A., and S. Morgenbesser. 1960. *Philosophy of Science*. Meridian Books, New York

Schrodinger, E. 1956. *What is Life?* Doubleday Anchor Books, New York

Toulmin, S. 1960. *Philosophy of Science*, Harper Torchbooks, New York

Articles in journals:

Atomic Theory Models. Mentioned in 1956 *Sci. Am.* 195 [5] 93

Duveen, D. I. 1956. "Lavoisier." *Sci. Am.* 194 [5] 84

Organic Chemical Reactions. Mentioned in 1957 *Sci. Am.* 197 [5] 117

Pfeiffer, J. E. 1948. "Enzymes." *Sci. Am.* 179 [6] 28

Wilson, M. 1954. "Priestley." *Sci. Am.* 191 [4] 68

FILMS

Laws of Conservation of Energy and Matter, 1958, (sd, b&w or c, 8 min), p or r, Coronet

Oxidation and Reduction, 1932, (sd, b&w, 11 min), p or r, EBF

Oxygen, 1947, (sd, b&w or c, 11 min), p or r, Coronet

The Multicellular Animal, Part IV: *Respiration*, No. 4, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 5 LIVING CHEMISTRY

RATIONALE

The title of this chapter is the key to its presentation to students. It is a chapter on chemistry, but it is also a chapter on chemistry in relation to the living organism. The student is not taking a course in chemistry, and should not be taught as if he were; thus, the chemical formulae and

diagrams of this chapter are not "something to be learned," but rather "aids to learning something." A knowledge of modern biology is predicated on an understanding of rudiments of chemistry as they apply to living systems. It is to this—an understanding, but not a mastery, of living chemistry—that Chapter 5 is addressed. Every effort should be made to relate the chemical processes discussed with the living systems in which they occur.

Among the critical points are definitions of elements, atoms, and molecules. For this purpose air is shown to be a mixture, water a compound, and diamond an element. The structure of elements is dealt with by an emphasis upon their electrons as the chief determiners of chemical behavior. Reactivity is related to completion of electron shells in the reacting elements. Organic molecules, with emphasis on the carbon they contain, provide an additional insight into chemical properties in terms of different substances with the same formulae; the relative position of atoms, as well as their number and kind, is a determiner of the chemical nature and reactivity of substances.

Compounds of cells are dealt with, with emphasis on water as their most common constituent. Ionization and pH are introduced as they pertain to chemical reactions in cells. Proteins, carbohydrates, and fats are discussed, and the similarities in the synthesis and hydrolysis of each are emphasized.

Students approach the end of the chapter with their first reference to nucleic acids and nucleotides. DNA, RNA, and ATP are mentioned; their nature and their roles in living systems will be studied in several chapters, beginning with Chapter 6 and ending with Chapter 32. Chapter 5 itself concludes with a brief review of the role of carbon as the most versatile element in organic compounds.

It is essential that an adequate background be laid in elementary chemistry in order that students can understand the physiological processes to be introduced later. However, too much chemical detail is to be avoided as vitiating the effect of the living aspects of the chemistry. There is no magic formula for locating the middle path between too much and too little; the teacher must make the decision for each class.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 116)

1. Blown into a balloon, air will cause the balloon to burst. Pumped into tires, air will support the weight of huge trucks. As seen in Chapter 4, air contains a substance that supports life, as well as another substance that snuffs out candles. All these observations indicate the presence of matter.
2. When one part of the air (oxygen) is removed, other unaffected gases are left. In addition, there are traces of many other gases in relatively constant but slightly varying amounts. If air were an element it would be composed of only one kind of atom.
3. Water could be evaporated and the sugar recovered, which would indicate that the sugar had not combined chemically with the water.
4. Water and salt can be broken down by electrolysis into their respective elements. Wood is not subject to electrolysis.
5. The activity of an atom is based on the number of electrons it possesses. Any atom with 2, 10, or 18 electrons has filled its outer electron shell and does not need to lose or gain an electron to achieve

stability. The neon atom, with 10 electrons, exists in a stable state and does not readily combine with any other element.

6. Chemical compounds are formed chiefly by electron transfers or electron sharing between atoms. Atoms that in association with one another share, gain, or lose electrons in their outer shells achieve greater stability by this chemical bonding.
7. When table salt is dissolved in water, the sodium and chlorine separate (as positive sodium and negative chloride ions); this is a characteristic of the dissolving of compounds formed by ionic bonding. When sugar is dissolved in water, its molecules do not break up, because the elements in the molecules are bound together by covalent bonds (in which electrons are not "gained" or "lost," but shared by the component atoms).
8. Proteins are built of about 20 kinds of amino acids, and most protein molecules contain 300 to 3000 animo-acid subunits. Just as an enormous number of different word-groupings or sentences could be constructed from 300 to 3000 letters of a 20-letter alphabet, so can an enormous number of different proteins be constructed of different chemical linkages of amino acids.
9. a. It is the best solvent known.
   b. It provides an effective environment in which many chemical reactions can occur, as substances go into solution in it.
   c. It is a good medium for diffusion of molecules and ions.
   d. It is a relatively stable compound.
   e. It ionizes to a slight extent.
   f. It is nontoxic.
10. Proteins are the most abundant type of organic compound in living material. They are large and complex molecules, differing from carbohydrates and fats in being made up of amino acids, which contain nitrogen in addition to carbon, hydrogen, and oxygen.
11. Sanger's determination of the structure of insulin (the first protein to have its structure completely worked out) helps give us a fuller understanding of living processes, because many of the properties of life are reflections of the structure and function of specific proteins.
12. Nucleic acids are chainlike molecular compounds not too unlike proteins; nucleotides are the subunits of which nucleic acids are synthesized. Nucleic acids such as DNA and RNA have a key role in inheritance and serve to direct protein synthesis. Nucleotides such as ATP have a prime role in providing energy for the cells' activities.

REFERENCES

In the *Teachers' Handbook*, Chapter 7 (page 262) provides explanatory material on molecules and atomic weights. Chapter 9 (page 283) deals with atomic structure, and Chapter 10 (page 316) with chemical bonds.

Useful books:

Baldwin, E. 1948. (Rev. ed. in preparation.) *An Introduction to Comparative Biochemistry*. Cambridge University Press, New York

Harris, R. 1961. *Protein Biosynthesis*. Academic Press, New York

Kosower, E. M. 1962. *Molecular Biochemistry*. McGraw-Hill, New York

Lwoff, A. 1962. *Biological Order*. Massachusetts Institute of Technology Press, Cambridge (Mass.)

Neurath, H. 1963. *The Proteins: Composition, Structure, and Function*, Vol. I. Academic Press, New York

Porter, G. 1962. *Chemistry for the Modern World*. Barnes and Noble, New York

Sanderson, R. T. 1962. *Teaching Chemistry with Models*. Van Nostrand, Princeton (N.J.)

FILMS

Cell Biology, Part I: *From Atoms to Organisms*, No. 12, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Cell Biology, Part I: *Chemical Organization of the Cell*, No. 4, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Conquest of the Atom, 1958, (sd, c, 22 min), p, IFB

Carbon and Its Compounds, 1949, (sd, b&w or c, 11 min), p or r, Coronet

Elements, Compounds, and Mixtures, 1961, (sd, c, 34 min), p or r, MLA

Ionization and Ionic Equilibrium, 1960, (sd, b&w or c, 15 min), p or r, Indiana

Chapter 6 THE PHYSIOLOGY OF CELLS

RATIONALE

Chapter 6 serves a dual purpose: It relates the chemistry of Chapter 5 to (1) the microstructure of the cell, and (2) the energy cycle of the cell. Chapter 6, then, is a further development of both the structure and the living functions of cells.

The chapter begins with a discussion of energy and the introduction of enzymes as specific proteins that serve as organic catalysts. Students meet again the process of hydrolysis first encountered in Chapter 5. The properties of enzymes and the factors that influence enzyme action are briefly discussed. The role of coenzymes is introduced at this point.

The parts of a cell (first mentioned in Chapter 3) are next reviewed in terms of their structure and function. The cell wall of plant cells and the differentially permeable cell membrane that controls movement of substances into and out of the cell, principally through diffusion, are of consequence here. Note that the term osmosis, denoting the diffusion of water, is not utilized, as it serves no useful purpose apart from augmenting the students' vocabulary.

The discussion of the endoplasmic reticulum points up that knowledge of structure alone does not necessarily explain function. The role of ribosomes in making protein from amino acids, and the use of centrifugation as a technique for cell study, are both discussed here (and protein synthesis will be discussed again in Chapter 32).

The energy used in cell metabolism is defined in terms of chemical bond energy, released by the oxidation of glucose and stored in ATP. In the energy story, a number of heretofore unrelated facts are tied together. Specific enzymes are shown to catalyze the breakdown of glucose, given energy from ATP to start the reaction. The electron transport chain and

the role of coenzymes (including DPN) are dealt with in terms of an energy cycle that makes 38 molecules of ATP for every molecule of glucose broken down. The role of fats and proteins in this energy story and the knowledge that the ultimate source of the energy (traced back through photosynthesis) is the sun serve to coordinate much of the material of the past several chapters.

In dealing with the cell nucleus, DNA is briefly discussed but will be taken up in greater detail in later chapters (mainly in Chapter 32). The chapter also introduces the cell's Golgi bodies, centrioles, and centrosomes, but makes no point of detailed discussion of them, since they will be mentioned in other connections later in the text.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 139)

1. Food is used as a source of energy to maintain the living state and as a source of materials to be converted into more living matter.
2. In the laboratory, if sugar is burned it will unite with oxygen, form water, carbon dioxide, and a carbon residue, and release a great deal of energy and heat at a relatively high temperature. In the body, the same end result is achieved with no violence, no high temperature, and no tremendous release of heat, because of the gentle stepwise release of energy regulated by enzymes and coenzymes.
3. Enzymes are proteins that act as organic catalysts, speeding the rate of reactions. Coenzymes are molecules that are essential to the chemical reaction controlled by an enzyme; like enzymes, they are not used up in the reaction. They are usually much smaller in molecular structure than proteins, and the same coenzyme may assist several different enzymes.
4. (See Figure 6-1, page 121.) The model includes the assumption that the substrate (or substance acted upon by an enzyme) fits into a portion of the surface of the enzyme molecule, where chemical bonds are formed or broken without the enzyme itself being altered. The enzyme thus is available to catalyze additional reactions with more of the substrate.
5. Enzymes work best within specific temperature ranges; they are made ineffectual or destroyed by high temperatures. They are specific, one enzyme usually controlling one type of reaction in the cell. Enzyme action is influenced by the amount of enzyme present, the amount of substrate present, the pH of the solution or cell, and the temperature.
6. The electron microscope shows the cell wall to be principally a network of cellulose fibers. In thick cell walls the fibers are arranged in layers forming a crisscross pattern, which gives strength. The nature of the cell membrane is not so well clarified by the electron microscope; the membrane is made of lipid (fatty) and protein layers and may have pores, although the evidence is not conclusive.
7. By centrifugation.
8. The cell membrane controls the passage of materials into and out of the cell.
9. Proteins have the more potential energy.
10. ATP has two terminal, high-energy phosphate bonds. Energy for cell activities is usually made available by splitting the ATP molecule at

the outermost high-energy phosphate bond. Energy can be stored in the molecule again by replacing the bond.

11. The mitochondria contain the enzymes and electron-transport chain that are essential in releasing the energy (mostly from glucose) used to convert ADP to ATP. Mitochondria therefore provide the ATP from which energy is released in a cell.
12. The energy of glucose is transferred to ADP to make ATP.
13. The enzymes control steps in the oxidation of glucose and the breakdown of ATP to provide slow, stepwise energy release without cellular destruction.
14. When proteins are used for energy, they first are converted to amino acids and then to pyruvic acid, which is broken down in the mitochondria. Fats are first hydrolized to fatty acids and glycerol. The fatty acids are then oxidized in the mitochondria in much the same way as pyruvic acid is broken down.

REFERENCES

Chapter 5 of the *Teachers' Handbook* (page 229) covers energy and Chapter 6 (page 242) deals with energy in light. Chapter 8 (page 269) explains gases and kinetic energy. Chapter 12 (page 353) is concerned with biochemistry.

Useful books:

Baldwin, E. 1962. *The Nature of Biochemistry*. Cambridge University Press, New York

Harrow, B., and A. Mazur. 1962. *Textbook of Biochemistry*, 8th ed. Saunders, Philadelphia

Schneider, Leo. 1964. *You and Your Cells*. Harcourt, Brace & World, New York

Swanson, C. P. 1960. *The Cell*. Prentice-Hall, Englewood Cliffs, (N.J.)

Articles in journals:

Holter, H. 1961. "How Things Get Into Cells." *Sci. Am.* 205 [3] 167

Lehninger, A. 1960. "Energy Transformation in the Cell." *Sci. Am.* 202 [5] 102

———. 1961. "How Cells Transform Energy." *Sci. Am.* 205 [3] 62

Robertson, J. D. 1962. "The Membrane of the Living Cell." *Sci. Am.* 206 [4] 64

Stein, W. H., and S. Moore. 1961. "Chemical Structure of Proteins." *Sci. Am.* 204 [2] 81

FILMS

Cell Biology, Part I: *What is a Cell?* No. 3, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Cell Biology, Part I: *Cell Respiration*, No. 5, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Cell Biology, Part I: *Patterns of Energy Transfer*, No. 6, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Cell Biology, Part I: *Transfer of Materials*, No. 7, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 7 THE REPRODUCTION OF CELLS

RATIONALE

In this chapter, cellular reproduction is viewed on the basis of mitosis and meiosis. It is important that students not only understand these processes, but how biologists came to conclusions regarding them. The historical theme is an important part of this chapter. An even more important part, however, is the fact that both the processes of meiosis and mitosis must be related to DNA and the problem of genetic continuity. At this particular time students are expected to understand no more than that the chromosomes contain the DNA and are divided equally among the cells in the process of mitosis. This, however, should be discovered by the student and not given as an introduction that will vitiate the nature of inquiry built into this chapter.

After the student has mastered mitosis, the question of genetic continuity is brought up by means of a discussion of what would happen if an organism's sex cells had the same complement of chromosomes as its other cells. Students are brought to the realization that a special mechanism must prepare sex cells, in order that the chromosome number will remain the same in succeeding generations. Meiosis is thus approached as it originally was predicted by the thinking of August Weismann. Beyond seeing how it was predicted and confirmed, students proceed no further at this time. A detailed study of meiosis and genetic continuity will be found in Chapter 31, as a part of the later coverage of genetics.

Some teachers may notice the omission of certain terms once considered "standard" in the study of mitosis. The so-called "phases" of mitosis—"interphase," "prophase," "metaphase," "anaphase," and "telophase," have been deliberately omitted as they contribute nothing to the understanding of the process, but rather detract from its dynamic nature by setting up in the students' minds the mistaken idea of artificial and static stages. It is hoped that teachers will not reintroduce these terms; their long history of use cannot be defended.

It is also to be noted that the term "monoploid," rather than "haploid," is used in relation to meiosis. This is a relatively simple matter of a change that is more semantically defensible in conjunction with the related term "diploid."

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 153)

1. Genetic continuity conveys the meaning of production of offspring similar to the parent, generation after generation. A frog or a chicken illustrates genetic continuity in that the fertilized eggs of the species always result in the production of more frogs or chickens, never another kind of organism.
2. The basic problem of cell division is the mechanism ensuring genetic (and therefore, structural and functional) continuity.
3. Fleming's observations on living cells were necessary in order to make sure that the inclusions seen in fixed and stained preparations were not merely artificial results of the fixing and staining.

4. The centrioles migrate, each with a surrounding centrosome, to opposite sides of the nucleus at the beginning of the mitotic process.
5. The chromosome complement is always present in the nucleus, even though it is difficult to observe at all times.
6. Large numbers of dividing cells will be found anywhere that is a region of growth in the organism. They will also be found anywhere that certain types of cells die and are replaced (the skin, for example).
7. The most important result of the mitotic process is that it insures genetic continuity. This is brought about because each daughter cell will have DNA identical, or nearly so, to that of the parent cell.
8. Raw materials move from the cytoplasm into the nucleus to form more DNA and protein, and each of the original chromosomes replicates itself (but the replicas do not separate).
9. Eight chromosomes.
10. Further study will give us knowledge of how the mitotic apparatus functions.
11. The phase microscope and biochemical techniques have demonstrated the existence of the spindle fibers in living cells.
12. Because the chromosome number remains constant generation after generation. Since a fertilized egg is formed by the union of an egg and a sperm, there cannot be the full chromosome number in each egg and each sperm, or else the resultant fertilized egg would contain twice as many chromosomes as the cells of the parents.
13. Meiosis results in eggs and sperms that have half the number of chromosomes characteristic of other cells in the parent organisms.

REFERENCES

Useful books:

Levine, L. (ed.), 1963. *The Cell in Mitosis*. Academic Press, New York Proceedings of a symposium held at Wayne State University, Detroit, November, 1961.

McLeish, J., and B. Snoad. 1958. *Looking at Chromosomes*. St. Martin's Press, New York

Swanson, C. P. 1960. *The Cell*. Prentice-Hall, Englewood Cliffs (N.J.)

Articles in journals:

Mazia, D. 1953. "Cell Division." *Sci. Am.* 189 [2] 53

——1961. "How Cells Divide." *Sci. Am.* 205 [100] 3

Swann, M. M., and J. M. Mitchison. 1958. "The Mechanism of Cleavage in Animal Cells." *Biol. Rev.* **33** p. 103

FILMS

Cell Biology, Part I: *Cell Reproduction*, No. 11, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Mitosis, 1961, (sd, b&w or c, 32 min), p or r, EBF

Mitosis in Endosperm, (si, b&w, 34 min), p or r, A. Bajer

Genetics, No. 3: *Mitosis*, 1960, (sd, b&w, 30 min), p or r, McGraw-Hill

Genetics, No. 4: *Meiosis*, 1960, (sd, b&w, 30 min), p or r, McGraw-Hill

Plant Growth and Mutation in Tradescantia virginica L., 1952, (sd, b&w, 11 min), p or r, Phase

Chapter 8 THE BALANCE OF NATURE

RATIONALE

Chapter 8 is in part a new perspective of the first seven chapters, a transition from the cell to the organism. It also is an introduction to the ecological balance of life, as well as an introduction to the subsequent chapters dealing with the diverse kinds of organisms.

Life at the two levels of organization already studied—(1) atoms and molecules, and (2) cells—is reviewed, and students are led to the realization that they cannot answer at these two levels all questions relative to life. The students are then led, logically, to succeedingly higher levels of biological organization: first, aggregations of cells into tissues (with epidermis as an example); and on, in turn, to organ systems, entire organisms, the species, community, and biosphere. Each of these levels is briefly defined and briefly discussed; they will be elaborated in various of the later chapters.

Here students become acquainted with the influences of the past on organisms of today—by genetic continuity and by evolution. There is a brief discussion of the evidences for evolution, including fossil remains, and the mechanisms of evolution which are here considered to be mutation and natural selection. As some of the later chapters deal with evolution in considerable detail, the main impact here is on the brief introduction of evidences and mechanisms leading toward diversity of organisms, which will then be elaborated upon in the following sections on microorganisms, plants, and animals.

Here also, students get their first introduction to ecology, in the relationship of organisms one to another in the community. First, species relationships are discussed, and secondly, community relationships, including the idea of producers and consumers and the cycling of essential materials of the biosphere. One of the cycles dealt with is the carbon-hydrogen-oxygen cycle; another is the nitrogen cycle. In both, the student can see the involvement of organisms in the cycling of compounds containing these elements.

The study of cycles leads logically to a further consideration of organisms and their environment—for example, ecological concepts such as the food web, colonization, and succession. Here again the topics are intended to help set the framework in which students are to consider the diverse organisms to be covered in the next three sections of the book. In some of the later chapters and laboratory exercises students will deal with these ecological concepts in greater detail.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text pages 177-78)

1. Living organisms are affected by one another in competing for food, for light, for types of soil, for water, for mates, for places to live, and in many other ways. Organisms of the same species may band together for protection, mating, or—as in the case of social organisms—to share aspects of communal living. Organisms may affect each other adversely or may interact in ways helpful to one another. The kinds and numbers of plants will in part determine the distribution of animals, which in turn affects the plants as the animals feed upon

them. The relationships of living organisms are extremely complex, but when one organism in a community is affected, it directly or indirectly affects all others.

2. The biological influences of the past have determined what kinds of organisms there are today. The methods of reproduction of organisms today, their overall genetic make-up, and their interrelationships in the biosphere—all are determined by influences of the past which selected from among the organisms of the past those that became the ancestors of organisms today.
3. Fossils tell us about the life of the past, and about the types of animals and plants that once existed. Because of our ability to date fossils, we can determine not only the kinds of organisms that lived in the past, but roughly <u>when</u> each of them lived. Thus we can trace changes in organisms through time.
4. Mutation provides new characteristics in organisms. These changes in genes are hereditary and, if adaptive, are perpetuated. If the changes are not adaptive they may upset the carefully adjusted physiology of the organisms in which they occur; the result would be extinction.
5. By natural selection, organisms with mutations that have adaptive value tend to survive and become the parents of ensuing generations. Thus the species evolves toward populations of organisms with the mutant characteristics. Harmful mutations, on the other hand, are selected <u>against</u>; organisms afflicted with them tend <u>not</u> to survive.
6. A species is a population of similar organisms, interdependent upon one another, and (in sexually reproducing organisms) interbreeding with one another. It is the unit of evolution. As an entity, it does not depend on the survival of each of its members and thus represents a level of biological organization because of this identity.
7. A community is a self-sufficient unit in that there is a source of energy capable of being captured by the members of the community, and a mechanism of supplying necessary chemical substances and keeping them in balance between the living members and nonliving environment of the community.
8. This is an open-ended question depending upon the pond community with which one began. Certainly the balance in the pond would be changed to some degree, at least temporarily. If we assume a simple relationship of an energy source from the sun, with producers trapping this energy by means of photosynthesis, then an increase in the numbers of the producers would support a corresponding increase in numbers of consumers. A sudden increase in a consumer population, however, would deplete the numbers of organisms on which it feeds, and lead to the sudden reduction by starvation of the population that first increased. None of these changes is likely to be permanent, for such changes commonly do occur, usually seasonally, in pond communities. A new balance is quickly reached, and life goes on.
9. The decomposers in a biological community return the chemical compounds of the bodies of dead organisms, and of the waste products of living organisms, to the environment in a form usable by other organisms.
10. Microorganisms, in the process of decomposing dead plants and animals, make carbon available in the form of carbon dioxide to be used in the carbon-hydrogen-oxygen cycle. Without these microorganisms,

the carbon in the bodies of the dead would be fixed and removed from the cycle. As dead organisms accumulated, the usable carbon supply of the atmosphere would be decreased, and photosynthesis would slow down or halt; thus, oxygen, too, would become unavailable. The decomposers, such as microorganisms, make it possible for usable supplies of carbon, hydrogen, and oxygen to remain available instead of becoming fixed in organic compounds.

Microorganisms also play an important part in the nitrogen cycle, for the proteins and amino acids of dead organisms are generally useless for green plants. Some species of bacteria and fungi can convert these useless compounds into ones usable by plants for synthesizing their own proteins. Some bacteria oxidize ammonia to nitrites, and other bacteria then oxidize the nitrites to nitrates. Nitrates are of vital importance to green plants, which cannot use atmospheric nitrogen for their nitrogen needs. Certain nitrogen-fixing bacteria and algae, however, are capable of utilizing atmospheric nitrogen in their own metabolism and converting it into nitrogen-containing substances that can be used by plants in making proteins and nucleic acids. Thus, microorganisms play an important part in the nitrogen cycle, as well as the carbon-hydrogen-oxygen cycle; without the microorganisms, both cycles would be disrupted, and all life might slowly come to an end.

11. A food web links together a whole community of living things in a complex relationship of feeding and being fed upon. It indicates the transfer of energy from producer (green plants) through a chain of consumers, with a number of alternate pathways. The greater the number of alternate pathways in a food web, the more stable the community of living things that form the web.

12. a. Plants and animals would repopulate the island by being borne to it on the wind, by floating to it on the water, or by being carried by birds or other animals.

    b. The first organisms to appear would probably be those whose spores or seeds could be airborne or waterborne to the island. Most of the first animal organisms would be either airborne or capable of locomotion through the air by flying, or through the water by swimming or floating. Probably the very first inhabitants would be fungi and algae, followed by coastal plants whose seeds had been carried to the island over the water. These would probably be followed by flying insects and birds.

    c. The climax community of plants and animals would undoubtedly resemble the climax community of the area from which these organisms had originally come, and would undoubtedly also be similar to the climax community on the island prior to the volcanic eruption.

13. A food web is altered when the environment changes and places some of the organisms of the web under a stress of temperature, drought, excess moisture, or fire, for example. These stresses may alter the numbers of producers or consumers, or change the complexion of the original food web by completely eliminating certain forms. For example, moisture-adapted producers and consumers would be reduced in numbers or eliminated, at least temporarily, if a drought were to occur.

REFERENCES

Useful books:

Kendeigh, S. C. 1961. *Animal Ecology*. Prentice-Hall, Englewood Cliffs (N. J.)

Lemon, P. C. 1962. *Field and Laboratory Guide for Ecology*. Burgess, Minneapolis

Oosting, H. J. 1956. *A Study of Plant Communities*, 2nd ed. W. H. Freeman, San Francisco

Seeley, H. W., and P. J. Van Demark. 1962. *Microbes in Action*. W. H. Freeman, San Francisco

Sheppard, P. M. 1958. *Natural Selection and Heredity*. Hutchinson & Co., London

Sistrom, W. R. 1962. *Microbial Life*. Holt, Rinehart and Winston, New York

Slobodkin, L. B. 1961. *Growth and Regulation of Animal Populations*. Holt, Rinehart and Winston, New York

FILMS

Ecology, Part IX: *Plant and Animal Distribution*, No. 1, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *Population Ecology*, No. 2, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX; *Energy Relations*, No. 3, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *Limiting Factors*, No. 4, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

The Multicellular Animal, Part IV: *The Animal and the Environment*, No. 12, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

The Community, 1962, (sd, b&w or c, 11 min), p or r, EBF

Succession—From Sand Dune to Forest, 1961, (sd, b&w or c, 16 min), p or r, EBF

What is Ecology? 1962, (sd, b&w or c, 11 min), p or r, EBF

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Chapter 9 VIRUSES—THE SMALLEST LIVING THINGS

RATIONALE

Chapter 9 again introduces the problem of the definition of "living." The viruses present particularly interesting problems in relation to this question. Students will be led to the conclusion that viruses are living in that they show the property of replication (even though this occurs only in the cells of the host) and that they also display genetic recombinations and mutations which are similar to those in living systems. The organizational position of the virus is a little above the level of complex molecules, but below that of cells.

The approach to the virus story is through historical perspective, reintroducing Louis Pasteur and subsequent men whose experiments demonstrated the existence of the virus. As was the case with the process of meiosis, viruses were discovered indirectly—there being at the time no known way to isolate them, or to view them with the available types of microscopes. Student motivation should be high for this type of "cerebral" detective work, and higher still because they have heard so much but know so little of viruses.

One very broad aim is served by this chapter. Through the discussion of viruses, students will learn more of the organizational "leap" from the level of the chemistry of complex molecules to the level of a living thing. Life—as the students will begin to recognize—exists at various stages of complexity of organization, of which the virus is currently the most simple.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 191)

1. The ability of the tobacco-mosaic virus to increase in amount and to spread through infected plants caused Beijerinck to attribute life to it.
2. The electron microscope, with its tremendous power of magnification and resolution, made it possible for the first time to "see" that the tobacco-mosaic virus existed as individual particles. The shape and even the structural composition of the virus particles could then be studied.

3. In order to reproduce, a virus in its inactive state must come in contact with a living host cell and must intrude its DNA or RNA into the host cell and assume control of the cells' biochemical activities. Thus, the growth and reproduction of viruses are limited by their ability to invade host cells and to multiply therein. We interpret these limitations by classing viruses as parasites. Furthermore, these and other limitations lead us to classify viruses as the simplest known living things.
4. There is no absolute answer to this question. All plant viruses contain a core of RNA. Most bacterial and animal viruses contain a central core of DNA. However, some animal viruses, like the plant viruses, have a core of RNA.
5. Virus particles are reproduced in a host cell by diverting the cell's biochemical activities to the production of virus material. The reproduction may be immediate, destroying the host, or gradual; in the latter case the virus DNA attaches to the host cell's DNA and gears its replication to the growth and reproduction cycle of the cell.
6. In the case of the bacteria that have been associated with diptheria, only those bacterial cells that contain a specific phage DNA produce the poison that causes the disease. Thus, it appears that the phage DNA modifies the nature of the bacterial cells it invades. Other, similar, bacterial cells remain harmless. This discovery focuses the attention of investigators on the role of viruses in certain bacterial diseases.
7. The living features of viruses are their possession of DNA or RNA, their ability to reproduce themselves when inside host cells, and their ability to perform genetic recombinations during the reproductive process. Their nonliving characteristics include the property of crystallization as individual particles, their inert nature outside of the host cells, and their lack of enzyme systems.
8. The large number of viruses that can reproduce in a short period of time makes them excellent materials for genetic studies; handling such large numbers of more complex organisms would be difficult in terms of both space and time. The relative simplicity of viruses also is helpful in genetics studies; a genetic change is not as likely to go unnoticed as in a complex organism with untold thousands of genetic characteristics.

REFERENCES

Useful books:

Burrows, W. 1963. *Textbook of Microbiology*, 18th ed. Saunders, Philadelphia

Cunningham, C. H. 1963. *A Laboratory Guide in Virology*. Burgess, Minneapolis

Fraenkel-Conrat, H. 1962. *Design and Function at the Threshold of Life: The Viruses*. Academic Press, New York

Hawker, L. E., *et al*. 1960. *An Introduction to the Biology of Microorganisms*. Arnold, London

Pollard, M. 1961. *Perspectives in Virology*. Burgess, Minneapolis

Sistrom, W. R. 1962. *Microbial Life*. Holt, Rinehart and Winston, New York

Weidel, W. 1959. *Virus*. University of Michigan, Ann Arbor (Mich.)

Article in journal:
Horne, R. W. 1963. "The Structure of Viruses." *Sci. Am.* 208 [1] 48

FILMS

Microbiology, Part II: *Viruses*, No. 9, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Virus, No. 1: *Between the Living and the Non-Living*, 1960, (sd, b&w, 29 min), p or r, Indiana
Virus, No. 2: *Giant Molecules*, 1960, (sd, b&w, 29 min), p or r, Indiana
Virus, No. 3: *The Stuff of Life*, 1960, (sd, b&w, 29 min), p or r, Indiana
Virus, No. 4: *Viral Genes*, 1960, (sd, b&w, 29 min), p or r, Indiana
Virus, No. 5: *How a Virus Kills*, 1960, (sd, b&w, 29 min), p or r, Indiana
Virus, No. 6: *Threads of Life*, 1960, (sd, b&w, 29 min), p or r, Indiana
Virus, No. 7: *Killers and Carcinogens*, 1960, (sd, b&w, 29 min), p or r, Indiana
Virus, No. 8: *Cancer*, 1960, (sd, b&w, 29 min), p or r, Indiana.

Chapter 10 BACTERIA—PIONEERS OF CELLULAR ORGANIZATION

RATIONALE

The opening sentences of Chapter 10 indicate in provocative terms the ubiquitous nature of bacteria, enabling the teacher to introduce a discussion of the comparative distribution of living organisms and thus lead the students to comprehension of the worldwide distribution of bacteria. The chapter then introduces, by means of the historical approach, the discovery of bacteria and the development of bacteriology. The order of events as presented by the chapter allows the teacher to expand upon the relationship of technology and science; in this particular case, it was the invention of first the compound microscope, then the electron microscope, that made possible a comprehensive study of the life of bacteria.

The students, in their study of the shape, size, and structure of bacteria, have an opportunity to quantify observations about the relative sizes of living organisms. They should also be able to compare the complexity of cellular organization of a typical bacterium with that of typical cells studied earlier in the course. The presence in bacteria of a cell wall and DNA, but the absence of a definite nucleus or of mitochondria, offers interesting points for discussion and comparison between bacteria and cells studied earlier.

Students are introduced to the mechanism whereby a typical bacterium will manage to exist through unfavorable environmental situations. The endospore is the survival mechanism employed. In later parts of the text, students will meet other, similar survival mechanisms characteristic of other types of organisms.

Because different bacteria demonstrate so many different methods of nutrition, it is here that students compare the basic patterns of heterotrophic and autotrophic nutrition, and for the former, go on to investigate saprophytic and parasitic modes of life. In dealing with the parasitic ex-

istence of some bacteria, students will draw parallels between these bacteria, with their limited number of enzymes, and the viruses, which have no enzyme systems at all.

Reproduction, first discussed in terms of cell division in Chapter 7, is now reintroduced in terms of bacterial fission. The growth rate of a bacterial population can be compared to that of cells undergoing mitosis, or that of viruses reproducing as discussed in the previous chapter. A typical growth curve introduces students to the concept of limiting factors in population growth and explains why organisms never reach their theoretical potential in reproductive capabilities; food and other limiting factors are operative in the environment.

As a part of the discussion of bacterial reproduction, sexual reproduction is introduced for the first time in the biology course. Here, in the bacteria, occurs the simplest known form of sexual reproduction—the exchange of genetic material (DNA), first demonstrated by the elegant work of Lederberg and Tatum. The biological importance of sexual reproduction is also introduced, and will be referred to many times in future chapters. Students at this point should be brought to the realization that sexual reproduction in the biological sense is an opportunity for the introduction of a new source of variability in offspring. A contrast of sexual and asexual methods of reproduction can further illuminate this principle and its implied genetic benefits.

Thus, bacteria are utilized as a vehicle to introduce simple cellular organization, survival mechanisms, nutritional patterns, reproduction, and population-limiting factors.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 206)

1. The question is conjecture, but probably most if not all forms of life would begin to decline and to become extinct—if the earth were without bacteria. Bacteria are essential to the nitrogen cycle and the carbon-hydrogen-oxygen cycle; they fill so many other important roles in the web of life that an enumeration is impossible (they even manufacture a needed vitamin in our own bodies). The elimination of all bacteria would disrupt every community of life on earth—both in the seas and on the land.
2. Bacteria are difficult to classify because of their small size and because they do not fit the plant-animal pattern. The presence of a cell wall indicates similarity to plants. However, the absence of mitochondria and of a definite nucleus makes them rather atypical cells. Many are flagellated in the manner of certain one-celled animals. As if this were not enough, it is also difficult to decide whether they are unicellular or colonial organisms; they may or may not be clumped together. A variety of nutritional and reproductive patterns also helps make it difficult to classify them.
3. The presence of a definite cell wall and similarities to certain blue-green algae led Cohn to classify bacteria as plants.
4. The presence of DNA can be demonstrated in bacteria by selective staining. Observations under the electron microscope further show that the DNA of a bacterium is packed into a bacterial chromosome. Other experiments have been performed to show that bacterial genes have a linear arrangement similar to that of other organisms. Be-

cause DNA comprises the genetic material of living cells, and because it occurs in bacteria, a logical assumption is that it is the bacterial hereditary material.

5. Endospores allow the bacterial species to resist unfavorable environmental conditions for lengthy periods of time and thus preserve the species.
6. Saprophytic bacteria obtain their nutritive requirements by means of complex enzyme systems that break down organic wastes or remains of animals and plants and convert these materials to simpler compounds needed by the bacteria. Parasitic bacteria do not have these complex enzyme systems, and they must depend on the enzymes of their host organism to synthesize their essential nutritive requirements. Autotrophic bacteria have their own characteristic enzyme systems that enable them to synthesize their organic compounds from simple inorganic substances, either by photosynthesis or by oxidation of certain iron, sulphur, or nitrogen compounds.
7. The maximum rate of bacterial reproduction is limited by the availability of water and nutrients needed for survival and reproduction. In addition, bacterial populations usually produce toxic waste substances that by their accumulation begin to inhibit growth.
8. The experiments of Lederberg and Tatum are best interpreted as indicating that genetic recombination occurs in bacteria and that some kind of sexual process is responsible for this recombination. (See Figure 10-10, text page 203.)
9. The electron microscope has shown that pairs of bacterial cells will form little tubes (see Figure 10-12, text page 205) that make possible the physical transfer of genetic material from one bacterial cell to the other.

REFERENCES

Useful books:

Bisset, K. A. 1962. *Bacteria*, 2nd ed. Williams and Wilkins, Baltimore (Md.)

Seeley, H. W., and P. J. Van Demark. 1962. *Microbes in Action*. W. H. Freeman, San Francisco

Sistrom, W. 1962. *Microbial Life*. Holt, Rinehart and Winston, New York

Sussman, A. 1961. *Biology Through Microbes: A Laboratory Guide*. University of Michigan, Ann Arbor (Mich.)

Thimann, K. V. 1963. *Life of Bacteria*. Macmillan, New York

Articles in journals:

Hotchkiss, R. D., and Esther Weiss. 1956. "Transformed Bacteria." *Sci. Am.* 195 [5] 48

Wollman, E., and F. Jacob. 1956. "Sexuality in Bacteria." *Sci. Am.* 195 [1] 109

Zinder, N. 1958. "'Transduction' in Bacteria." *Sci. Am.* 199 [5] 38

FILMS

Microbiology, Part II: *Bacteria*, No. 8, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Simple Plants: Bacteria, 1958, (sd, b&w or c, 13½ min), p or r, Coronet

Bacteria—Friend and Foe, 1954, (sd, b&w or c, 11 min), p or r, EBF

Chapter 11 SMALL ORGANISMS OF GREAT ECONOMIC IMPORTANCE

RATIONALE

The emphasis of this chapter is upon those activities of bacteria that are directly or indirectly either harmful or helpful to man and his biotic world. The chapter is divided into two sections, the first dealing with harmful bacteria and the second with beneficial bacteria.

In the section developing the concept of bacteria that are harmful to man, the historical development of the germ theory of disease is traced from Hippocrates through Koch's use of the experimental method to identify a pathogen. Koch's postulates are presented. The concept of a pathogen, and the applicability of the concept to both plants and animals, is developed for student comprehension. The meaning of disease is reviewed, from the first use of the term in Chapter 1 through the last previous use, and the student is brought to the realization that diseases are of many different kinds, resulting from a number of different causes. The entry of a pathogen into the body and its subsequent activity result in one kind of disease.

With the development of the concept of infectious disease, the next subject, disease control, is easy to introduce. Here students learn about antigen-antibody phenomena, types of immunity, the historical development of artificial immunity, with the work of Jenner in vaccination as an example, and the use of antibiotics, disinfectants, and synthetics such as sulfa drugs.

In addition to infectious disease and its control, another topic related to the so-called harmful bacteria is the problem of food spoilage. Students are introduced to the methods of control of bacteria that invade food. Heat, cold, drying, or the use of chemical preservatives—or a combination of more than one of these methods, plus care in packaging or canning—account for our means of control of food spoilage.

The damage that bacteria do is more than offset by all the ways in which bacteria are useful, or even essential, to man. The essential role of bacteria in the carbon-hydrogen-oxygen and nitrogen cycles has been covered elsewhere (Chapter 8), but is mentioned again briefly before other beneficial aspects of bacterial activity are listed. From vitamin B_{12} synthesis to human digestion, and from the leather and cheese industries to all our uses of a controlled fermentation process, the beneficial aspects of certain bacteria weigh heavily in man's biotic world.

The topic of fermentation reintroduces methods of energy utilization within organisms by contrasting the energy pathways in anaerobic and aerobic metabolism. The amounts of energy released in each process, as well as industrial applications of fermentation, are made known.

Through a study of this chapter, students will come to comprehend the great variety of bacterial activities that influence them in their environment. Problems of disease, hygiene, public health, and the better utilization of bacterial activity can be introduced at this point to amplify and augment the materials presented in the chapter, but not, however, at the risk of crowding out the basic biology of the bacteria.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 229)

1. Koch's postulates are methods of inquiry for identification of pathogens. Their use led to the identification of bacteria as pathogens and proved Pasteur's hypothesis that bacteria can cause disease in animals and man.
2. The sharp reduction in the incidence of bacterial diseases in the United States is due to effective controls in the forms of vaccination and other immunizations, together with the use of antibiotics and chemosynthetic drugs.
3. Differences in environmental conditions in the host will partially determine in which tissues the pathogen will become established. Usually the site of invasion also affects the site of the infection. Knowing the site of invasion allows either preventive or remedial therapy to be undertaken.
4. In the case of the tetanus bacillus, unless the environment has a low oxygen content the organism will not grow and secrete its deadly toxin. In contrast, the bacillus that causes pneumonia requires an environment rich in oxygen; without adequate oxygen supplies, it will not survive to harm the host.
5. The more toxin a bacterium produces the greater will be its degree of virulence. Bacteria that secrete exotoxins are highly virulent, since the exotoxins can spread rapidly throughout the host by diffusion and circulation. Bacteria that secrete endotoxins have comparatively low virulence because the endotoxins are retained inside the bacterial cell and freed only if the cell is broken down.
6. Antibodies, being specific, will affect only one form of protein. Thus the body requires different antibodies to combat different diseases. If the antibodies were not specific they might attack the body's needed proteins and cause deficiency disease. Their specificity makes it safe for them to be introduced into the bloodstream, for they will react only with the foreign protein in question.
7. Jenner's observations that a person recovering from cowpox did not contract smallpox were the basis for his vaccination procedures. In effect, and without knowing the reasons why, he introduced artificial active immunity into the body by means of vaccination. His artificially induced active immunity has been followed in recent years by the development of vaccines for a wide variety of diseases, including polio.
8. When the body produces its own antibodies in response to the introduced foreign protein, the immunity is <u>active</u> and relatively long-lasting. When the body merely receives injections of antibodies produced in another animal, the immunity is <u>passive</u> and of relatively short duration.
9. The specific effects of an antibiotic can be determined by culturing pathogenic bacteria of different types and exposing them to paper disks that have been saturated with the antibiotic. Variations of the procedure will establish the relative effectiveness of different concentrations of the antibiotic as compared with different concentrations of other antibiotics.
10. Widespread use of antibiotics is discouraged for several reasons. (a) In addition to specific effects, antibiotics may produce side effects; thus, a person may become allergic to an antibiotic and suffer severe reactions when it is used a second or third time. (b) The use of anti-

biotics may practically sterilize the human intestine; the bacteria that aid digestion and vitamin synthesis may be as susceptible to the antibiotic as the suspected pathogen. (c) By natural selection, susceptible strains of pathogens will be killed by antibiotics, and their place in their biological communities may be taken by suddenly increasing populations of antibiotic-resistant strains that no longer have competition.

11. Some chemicals are used as disinfectants and antiseptics. They may be applied directly to surfaces or instruments to kill or retard the growth of bacteria. Other chemicals, of which the sulfa drugs are an example, can be taken orally to destroy bacteria within the body.
12. This question is a restatement of Question 1 at the end of Chapter 10. However, after completion of this chapter, students should be able to answer it in greater detail and with greater sophistication than they did on the first occasion of its use.
13. A freshwater organism placed in a strong brine solution will dehydrate; water will diffuse out of it into the surrounding brine, and the organism will either die or have its activities greatly retarded. Such an effect on bacteria would reduce the spoilage of foods placed in such a brine.
14. Bacteria provide vitamins, aid digestion, act as a source of enzymes, and are used in industry in processes such as tanning, cheese making, and fabric processing. The process of fermentation forms alcohol, acetic acid, and other products useful to man. (In Chapter 8, the role of bacteria in the phenomena of decay, nitrogen-fixation, and the carbon-hydrogen-oxygen cycles was elaborated.)
15. The study of fermentation led to an investigation of anaerobic metabolism and a contrast of aerobic and anaerobic metabolism as energy sources. In addition, the development of a better understanding of anaerobic respiration has indicated how early organisms could have existed on the earth without oxygen.

REFERENCES

Useful books:

Brock, T. 1961. *Milestones in Microbiology*. Prentice-Hall, Englewood Cliffs (N. J.)

Slanetz, L., *et al*. 1963. *Microbiological Quality of Foods*. Academic Press, New York

Stanier, R., and M. Doudoroff. 1963. *The Microbial World*. 2nd ed. Prentice-Hall, Englewood Cliffs (N. J.)

Wedberg, S. 1963. *Paramedical Microbiology*. Reinhold, New York

Article in journal:

Burnet, M. 1954. *"How Antibodies are Made."* *Sci. Am.* 191 [5] 74

FILMS

Microbiology, Part II: *The Germ Theory of Disease*, No. 10, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Microbiology, Part II: *Importance of Microorganisms*, No. 12, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Microorganisms: Beneficial Activities, 1958, (sd, b&w or c, 15 min), p or r, Indiana
Microorganisms: Harmful Activities, 1958, (sd, b&w or c, 15 min), p or r, Indiana

Chapter 12 MOLDS, YEASTS, AND MUSHROOMS

RATIONALE

This chapter introduces students to evolutionary relationships among living organisms. Here the problem of relationship is begun with slime molds and true fungi, shown to be more closely related to unicellular animals than to plants, a concept as new to many teachers as to most students. Today it is abundantly clear that fungi are neither plants nor animals, but only fungi—a separate type of organism. (They are included in the plant section of the textbook only until such time as their classification is clarified—perhaps within a separate kingdom.) Much of the distinction between life and nonlife was found difficult to make in earlier chapters, so in this chapter the distinction between plants and animals is thus shown not to be a simple "either/or" proposition. The true evolutionary significance of such organisms as slime molds and fungi is that <u>all</u> living organisms, plant and animal categories notwithstanding, are more closely related than students have been led to believe in the past. There exist numerous groups of organisms that show how arbitrarily distinguished from one another the "all-inclusive" plant and animal kingdoms really are.

In the evolutionary discussion of some of these organisms, early adaptation to a terrestrial environment and the modification of the reproductive cycle in order that these organisms could survive and reproduce on land is emphasized. Here again is an opportunity to reinforce the concepts of reproduction brought out in earlier chapters and point out the modification that such a process must undergo on land in contrast to the same process in a marine or other aquatic environment.

Just as in Chapters 10 and 11, which dealt with the bacteria, Chapter 12 covers both the biological nature and the economic importance of fungi. Students can make comparisons between the bacteria and the fungi regarding their edibility and harmful and beneficial uses. Problems of spoilage and decay, which were mentioned in the chapter on bacteria, are brought out in relation to the fungi, as are the problems of fungus diseases, which in many cases are as important as bacterial diseases. A specific group of fungi, the yeasts, are dealt with in some detail. They demonstrate both asexual reproduction by budding and sexual reproduction and thus afford an interesting type of life cycle.

The chapter concludes with a summary about the colonization of land and the necessary adaptations that have taken place through evolution to fit the fungi to a terrestrial environment. The theme of evolutionary adaptation to land is continued in the next chapter, with the study of green plants.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 242)

1. Animal-like characteristics of the slime mold plasmodium include mobility and the absence of a cell wall.
2. The fruiting stage and the thick-walled spores of the slime mold are plant-like features.
3. Terrestrial adaptations of *Rhizopus* include hyphae that absorb water and soluble nutrients, and that anchor the plant, and the production of large numbers of thick-walled spores that resist drying and can be dispersed by air or splashing water. Another terrestrial adaptation is the method of sexual reproduction, which occurs by the fusion of hyphae to form a zygote, without requiring free water as a medium for the transportation of gametes. The zygote has very thick walls, which like those of spores, withstand drying and other adverse terrestrial conditions.
4. Many primitive fungi and various of the true fungi produce flagellated cells at some point in their life cycle. These cells resemble protozoans and are unlike the reproductive cells of algae. Further studies of the primitive fungi have convinced biologists that these unusual aquatic organisms are not at all like algae, from which it was originally believed that fungi were evolved. Today the biologists are convinced that true fungi and their primitive relatives evolved from protozoans.
5. Some bacteria and fungi produce useful products from fermentation. Others produce antibiotics. Both bacteria and fungi are decomposers and play important roles in the cycles of nature. Some fungi, as well as some bacteria, produce diseases of both plants and animals. Fungi as well as bacteria cause tremendous amounts of spoilage.
6. The most classic case of far-reaching consequences of a fungus disease was that of the fungus disease of the Irish potato, which in the last century caused successive crop failures in Ireland. As a result, over a million Irishmen died of starvation and other diseases related to malnutrition, and another million and a half people emigrated to North America. The subsequent population shift produced marked political, social, and economic consequences. Similarly, any other fungus diseases that reduce the food supply of a rapidly expanding world's population will produce marked effects socially, politically, and economically.
7. Yeasts have economic importance in producing alcohol and carbon dioxide by their process of fermentation. Thus, they are utilized in the making of alcoholic beverages, and in making bread and other bakery products where the carbon dioxide causes the dough to rise.
8. The important adaptations that enabled fungi to live on land were: (a) the loss of flagellated reproductive cells and the accompanying evolution of new methods of sexual and asexual reproduction; (b) the evolution of protective layers around spores and zygotes; and (c) the evolution of hyphae, which grow throughout the immediate environment and obtain the kinds of nutrients that in ancestral aquatic forms were brought to the organisms by the surrounding water. The hyphae also support the sporangia, from which spores can easily be dispersed, and finally, hyphae are the structures that are modified for sexual reproduction.

REFERENCES

Useful books:

Bonner, J. 1959. *The Cellular Slime Molds*. Princeton University Press, Princeton (N. J.)

Gray, W. D. 1959. *The Relation of Fungi to Human Affairs*. Holt, Rinehart and Winston, New York

Large, E. C. 1940. *The Advance of the Fungi*. Dover, New York

Stakman, E., and J. G. Harrar. 1957. *Principles of Plant Pathology*. Ronald Press, New York

Articles in journals:

Ahmadjian, V. 1963. "The Fungi of Lichens." *Sci. Am.* 208 [3] 122

Avery, G. S. 1957. "The Dying Oaks." *Sci. Am.* 196 [5] 112

Bonner, J. T. 1956. "The Growth of Mushrooms." *Sci. Am.* 194 [5] 97

Bonner, J. T. 1963. "How Slime Molds Communicate." *Sci. Am.* 209 [2] 84

Emerson, R. 1952. "Molds and Men." *Sci. Am.* 186 [1] 28

Maio, J. 1958. "Predatory Fungi." *Sci. Am.* 199 [1] 67

Niederhauser, J., and W. Cobb. 1959. "The Late Blight." *Sci. Am.* 200 [5] 100

FILMS

Microbiology, Part II: *Fungi*, No. 6, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Plants, Part VII: *The Lower Fungi*, No. 4, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Plants, Part VII: *The Higher Fungi*, No. 5, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Fungi, 1960, (sd, b&w or c, 16 min), p or r, EBF

Life of the Molds, 1958, (sd, c, 21 min), p or r, McGraw-Hill

Budding Yeasts (Monilias) (Time-Lapse), 1947, (si, b&w, 4 min), p or r, ASM

Chapter 13 THE TREND TOWARD COMPLEXITY

RATIONALE

This chapter further develops the theme of evolution, directed now toward organisms that clearly are plants. In discussions of evolution, time becomes an important factor, and it is essential early in the discussions to help students comprehend that calendars and clocks are about as closely related to time in the evolutionary sense as the length of a city block relates to the distances between stars in space. The first question likely to be asked is, "How do we know how long ago fossil plants lived?" This is answered in the text with the discussion of the uranium-lead dating method, followed by a geologic time scale and a discussion of fossils as

evidences of life of the past. The fact that organisms of a cellular structure similar to algae and fungi have been found in Pre-Cambrian rocks 1.6 billion years old should give the student some idea of the span of evolutionary time being discussed. By the time the story becomes fairly continuously legible in the Pre-Cambrian rocks, primitive aquatic organisms having both autotrophic and heterotrophic nutrition are recognizable.

After the appearance of cellular organisms, another step in evolution led toward multicellular organisms, with a division of labor among the individual cells.

Sexual reproduction, previously studied in connection with bacteria, slime molds, *Rhizopus*, and yeasts, is met here again in *Chlamydomonas*, which like earlier examples, demonstrates the isogamous condition of the gametes. The student is introduced for the first time to heterogamy (demonstrated in *Oedogonium*), the characteristic gamete pattern to be found in the sexual reproduction of more advanced plants ard animals. With the development of heterogamy, the sex cells become recognizable as egg and sperm, the egg with a protective covering and the zygote often retained within the female organism.

Even though sexual reproduction in these algae is more advanced than in organisms studied earlier, spores are still produced—but the spores are unlike those previously studied, in being thin-walled.

The trend toward complexity is seen to continue with the development of alternation of generations as exhibited in *Ulva*. The development of a definite sporophyte and gametophyte continues throughout the plant kingdom with variations on the relative importance of gametophyte and sporophyte generations. The potential survival value of alternation of generations is believed to be by meiosis occurring prior to spore formation, thus creating a wide genetic variety of spores. Those spores that survive and develop into gametophytes lead to the production of gametes and future sporophyte generations.

The algae, which are the main emphasis of the chapter, are shown to carry on in their aquatic environment 90 percent of all photosynthesis, and a discussion of their potential use in space travel is here included. Other economic aspects of algae—for example, the wide variety of products for man, from food to filters—should also give the student an appreciation of the practical role algae play in today's world.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 259)

1. Organisms similar to fungal hyphae and spores, and colonies of cells very much like modern blue-green algae, have been discovered in Pre-Cambrian rocks at least 1.6 billion years old, indicating that fungi and blue-green algae were among the earliest of cellular organisms.
2. The Pre-Cambrian landscape was one without land plants or animals. It would be a hostile environment to plants that had not yet evolved effective structures that would protect them from drying out on the desiccating land surfaces.
3. *Chlamydomonas* represents the type of unicellular autotroph from which multicellular green plants are believed to have evolved, in that it has bright green chloroplasts and well defined cell walls. It contains the same two kinds of chlorophyll that are found in land plants,

and in similar proportions to their occurrence in land plants. Stored food in both *Chlamydomonas* and the green land plants is true starch.

4. A colony of many single cells can be distinguished from a true multicellular organism in that the multicellular organism exhibits a division of labor between its differentiated cells, while in a colony each cell is potentially self-sufficient and independent.
5. The development of sexual reproduction in the green algae introduced a factor of variability that increased the chances of favorable gametic combinations better adapted to survive on land. Asexual reproduction does not allow for such wide variation and subsequent adaptability.
6. The external appearance of the gametophyte and sporophyte generations of *Ulva* is similar. One, however, has 13 chromosomes per cell and produces gametes; the other has 26 chromosomes per cell and produces spores. The diploid number of 26 chromosomes is contained in the sporophyte and is reduced by meiosis to 13 in the monoploid spores. The gametophytes produced from the spores then are monoploid and produce monoploid gametes.
7. In alternation of generations, not only do the gametophyte and sporophyte generations alternate, but the monoploid and diploid number of chromosomes likewise alternate.
8. The green algae are most likely ancestors of green land plants because they resemble the green land plants in both their pigments and stored foods. They have evolved a multicellular body plan, developed heterogamous sexual reproduction, and demonstrate alternation of generations—all of which are features common to green land plants.

REFERENCES

Chapter 11 (page 331) of the *Teachers' Handbook* offers additional material on "Dating by Radioactive Isotopes."

Useful books:

Delevoryas, T. 1962. *Morphology and Evolution of Fossil Plants*. Holt, Rinehart and Winston, New York

Knobloch, I. 1963. *Selected Botanical Papers*. Prentice-Hall, Englewood Cliffs (N. J.)

Sinnott, E., and K. Wilson. 1963. *Botany: Principles and Problems*. McGraw-Hill, New York

Weisz, P., and M. Fuller. 1962. *The Science of Botany*. McGraw-Hill, New York

Articles in journals:

Bonner, J. T. 1950. "Volvox, a Colony of Cells." *Sci. Am.* 182 [5] 52

Milner, H. W. 1953. "Algae as Food." *Sci. Am.* 189 [4] 31

Weiss, F. J. 1952. "The Useful Algae." *Sci. Am.* 187 [6] 15

FILMS

Simple Plants—The Algae, 1962, (sd, b&w or c, 18 min), p or r, EBF

Microbiology, Part II: *Microorganisms with Chlorophyll*, No. 4, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Reproduction in Plants, 1958, (sd, b&w or c, 14 min), p or r, Coronet

Diversity of Plants, Part VII: *The Algae*, No. 2, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Plants, Part VII: *Algal Reproduction*, No. 3, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Life, Time and Change, Part X: *Rocks and the Record*, No. 1, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 14 THE LAND TURNS GREEN

RATIONALE

This chapter continues the story of plant evolution with the invasion of the land. Although primitive land plants existed early, as evidenced by Cambrian spores, more complete land fossils, demonstrating the existence of vascular plants, date from approximately 400-425 million years ago. As plants are believed to be the first invaders of the land, it is interesting to know that living things have occurred on land for only about one-tenth of the earth's existence.

Students are introduced to the special situations to which plants have had to adapt in order to be successful on land. First was the problem of obtaining water; this was solved by the evolution of rhizoids and roots. The retention of water, once it was obtained, was made possible partly by multicellularity, in which a relatively small number of cells are exposed to the environment, and partly by the development of a water-impervious layer of cutin on exterior surfaces of the plant. Also, the ability of some plants physiologically to withstand drying was a factor.

The problem of obtaining carbon dioxide from an environment relatively deficient in that compound depended upon the evolution of structures that could absorb their carbon dioxide from the air. Leaves with stomata were the evolutionary answer. The stomatal apparatus, paired with the chlorophyll content and the water-supplying vascular tissue of the leaves, made photosynthesis in complex land plants possible.

Heterogamy (introduced for aquatic plants in Chapter 13), the protection of the reproductive cells, and the evolution of a plant embryo formed the basis of the reproductive adaptations of terrestrial plants.

Alternation of generations, characteristic of all higher plants, is demonstrated in the moss with its dominant gametophyte generation, and its dependent, attached sporophyte generation. This is in contrast to the situation in the vascular plants, where the sporophyte is the dominant generation and the gametophyte is greatly reduced. (In flowering plants, the female gametophyte is reduced to as few as seven cells in the reproductive structures; the male gametophyte is reduced even further. Ultimately, this trend would lead to a single egg and a single sperm cell.)

In primitive vascular plants there are neither roots nor leaves. The text considers the evolution of leaves from a system of branches, and of stems and roots from other branches, some of them underground.

In the reproductive cycle of vascular plants, the evolution of protected sporangia, the retention of female spores, and the evolution of integumented seeds were essential terrestrial adaptations. Problems of fertilization in terrestrial plants are also discussed in this chapter, and the flagellated sperms of the nonvascular plants are contrasted to the pollen tubes that have evolved in flowering plants.

In summary, the chapter deals with the evolution of whole new organisms adapted to a new environment—the land areas previously uninhabited. Each structural part of complex land plants is analyzed for its nature and its role in the evolution of life on land.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 285)

1. Because they live in water, most aquatic organisms have no problem of obtaining water or retaining it. Supplies of oxygen and carbon dioxide are also readily available, dissolved in the water. The water's buoyancy makes supporting tissues in aquatic plants relatively unnecessary or unimportant, and the water provides an ideal medium for fertilization of eggs by swimming sperms, or for fertilization of isogamous flagellated gametes.
2. In colonizing the land, plants had to adapt by means of evolution to a relatively desiccating environment. They needed mechanisms for obtaining and retaining water. They also required a mechanism of support, and a means of distributing water throughout the plant tissues. For photosynthesis, they needed not only water and chlorophyll, but a usable source of carbon dioxide; this required another mechanism for absorbing carbon dioxide from the air. Plant reproductive structures also had to evolve, to insure fertilization in a terrestrial environment.
3. Primitive green land plants were able to survive because of: (a) a compact multicellular plant body and the ability to conserve water; (b) modification of photosynthetic tissues for the absorption of carbon dioxide; (c) special structures for the absorption of water; (d) heterogamy; (e) protection of reproductive cells; (f) formation of embryos; and (g) alternation of generations.
4. The simplest land plants conserve water by means of a compact multicellular plant body, which exposes relatively small numbers of cells to the drying effects of the atmosphere. In addition, the rate of evaporation from the surface cells is retarded by a waxlike coating of cutin.
5. In *Marchantia,* carbon dioxide is absorbed through pores (stomata) into an air chamber that has branching filaments of photosynthetic cells which allow the carbon dioxide to diffuse through their wet cell surfaces into the cytoplasm. This exposes a maximal amount of surface to the absorbtion of carbon dioxide.
6. Reproductive cells of land plants must be protected from drying out and from mechanical injury. In mosses, a protective multicellular layer is formed around the sperms or eggs, and leaflike structures help prevent drying of the sex organs.
7. The embryos of terrestrial plants develop inside the protective covering of female reproductive structures; thus they are protected from drying out and from mechanical injury. These are essential features for the survival of green plants on land.
8. In both plants and animals the obtaining of water, the conservation of water, the ability to use atmospheric gases for respiration, the development of reproductive structures permitting independence from an aquatic environment, and the development of supporting structures of some kind were parallel adaptations to the land environment. Both animals and plants adapted to the terrestrial environment by develop-

ing as multicellular organisms with heterogamous sexual reproduction and protected embryos.

9. Asexual reproduction permits the production of large numbers of resistant spores that can survive a variety of unfavorable environmental conditions. Sexual reproduction insures a maximum of genetic variability, important to evolution in a changing environment.
10. Man obtains nearly all his food from vascular plants. The wood of his home and his furniture is the product of vascular plants. The cotton and linen fibers in his clothes come from vascular plants, as do many medicines and most fuels (coal and peat, for example).
11. The earth's crust contains fossils of primitive vascular plants consisting of a system of forked branches of about equal size. These plants had no leaves or roots; underground branches functioned as roots, and aerial branches had stomata for the exchange of gases during photosynthesis. The branches had vascular tissues, epidermis, and cortex. Fossil spores indicate that the plants were sporophytes.
12. Small, one-veined leaves could have evolved as outgrowths from the naked branches of primitive plants, or from a reduction in size of part of the leafless branching system of primitive vascular plants. Many-veined leaves are a modification (through planation and webbing) of the forked branching system of primitive vascular plants.
13. The fossil record clarifies the origin of the multiveined leaf by providing fossilized remains of Devonian and Carboniferous plants that show developmental stages from the forked branching system to the webbed flattened system.
14. The roots of vascular plants have a central solid core of xylem tissue and a surface capable of absorbing water and dissolved minerals from the soil. They probably originated from the underground stems of primitive vascular plants, in which the central solid core of xylem was also a characteristic, along with water- and mineral-absorbing surface properties.
15. In primitive vascular plants living today (and in fossil relatives), the supporting tissue consists of a central solid rod. In larger, more complex vascular plants, stems are supported by one or more rings of vascular tissue, often organized into separate bundles.
16. The development of secondary wood tissues in vascular plants made possible the growth of tall plants of large size.
17. In heterosporous plants the spores are of different sizes and produce two different gametophytes, the female spore being retained and protected as it develops into a tiny female gametophyte.
18. "Free" water for fertilization in the more advanced land plants is unnecessary because of the development of pollen tubes that digest their way through the tissues of the female reproductive organs, and so reach the egg.
19. The development of fruiting structures provided additional protection of seeds from mechanical injury and from other unfavorable environmental conditions. Thus protected, the seed is better able to withstand the rigors of a terrestrial environment.
20. In carrying pollen from plant to plant, insects helped to increase the genetic variability of green land plants; it can be assumed, then, that natural selection and evolution proceeded more rapidly than would have been so if self-pollination had been the predominant pattern.

21. Divergent evolution is the process whereby two similar structures or organisms become increasingly different as a result of evolutionary changes. The sporophytes and gametophytes of land plants demonstrate divergent evolution in that the sporophyte generation has evolved toward complexity, while the gametophyte generation has evolved toward simplicity and complete dependence upon the sporophyte generation.

REFERENCES

Useful books:

Bold, H. 1960. *The Plant Kingdom*. Prentice-Hall, Englewood Cliffs (N. J.)

Delevoryas, T. 1962. *Morphology and Evolution of Fossil Plants*. Holt, Rinehart and Winston, New York

Fuller, H., and A. B. Carothers. 1963. *The Plant World*, 4th ed. Holt, Rinehart and Winston, New York

Galston, A. 1961. *The Life of the Green Plant*. Prentice-Hall, Englewood Cliffs (N. J.)

Milne, L., and M. Milne. 1959. *Plant Life*. Prentice-Hall, Englewood Cliffs (N. J.)

Muller, W. 1963. *Botany: A Functional Approach*. Macmillan, New York

Ray, P. M. 1963. *The Living Plant*. Holt, Rinehart and Winston, New York

Sinnott, E., and K. Wilson. 1963. *Botany: Principles and Problems*, 6th ed. McGraw-Hill, New York

Article in journal:

Newell, N. D. 1963. "Crises in the History of Life." *Sci. Am*. 208 [2] 76

FILMS

Evolution of Vascular Plants—Ferns, 1962, (sd, b&w or c, 17 min), p or r, EBF

Angiosperms: Flowering Plants, 1962, (sd, b&w or c, 21 min), p or r, EBF

Seed Germination, 1961, (sd, b&w or c, 15 min), p or r, EBF

Gymnosperms, 1961, (sd, b&w or c, 17 min), p or r, EBF

Multicellular Plants, Part III: *The Plant Organisms*, No. 1, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Leaves*, No. 3, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Roots*, No. 6, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Stems*, No. 7, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Flower Structure*, No. 10, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Flower Functions*, No. 11, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Variations on a Theme*, No. 12, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Life Story of a Fern, 1953, (sd, b&w, 16 min), p or r, UW

Life of a Plant, 1950, (sd, c, 11 min), p or r, EBF

Diversity of Plants, Part VII: *Early Land Plants*, No. 7, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Plants, Part VII: *The Bryophytes*, No. 6, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Diversity of Plants, Part VII: *Ferns and Their Allies*, No. 8, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Diversity of Plants, Part VII: *Gymnosperms*, No. 9, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 15 PHOTOSYNTHESIS—THE LINK BETWEEN TWO WORLDS

RATIONALE

The development of our current understanding of photosynthesis is introduced historically with references to van Helmont and Priestley, whose work was earlier referred to in Chapter 4. The discoveries leading to our knowledge of the involvement of water, carbon dioxide, and sunlight in photosynthesis are briefly described. The importance of photosynthesis to the animal world must be emphasized as the only process whereby energy becomes available to all heterotrophs.

The common photosynthetic organ of a green plant is the leaf, whose chloroplasts contain chlorophyll. The reason for the greenness of green plants becomes apparent in the paragraphs dealing with light and photosynthesis, in which it is pointed up that the green light is reflected, and certain other wavelengths absorbed heavily. On the basis of these observations, dramatically illustrated in Figure 15-3 (text page 289), an absorption curve can be constructed as shown in Figure 15-4 (text page 290).

We know that chlorophyll is the special substance that traps light energy and makes it available for those reactions involved in photosynthesis. In this section, however, students are led to understand that we do not completely understand either the process of photosynthesis or the detailed role that chlorophyll plays in the process.

In Chapter 14 it was pointed up that carbon dioxide is more abundant in aquatic than in terrestrial environments. This chapter points up the necessary plant adaptations for obtaining, in the terrestrial environment, adequate amounts of carbon dioxide for photosynthesis. The functioning of the guard cells to control the openings into the leaf is a fine example of an internal regulating mechanism. The role of the stomata in controlling water loss is also correlated with guard cell activity, and the necessity for control of water loss is sometimes apparently contradictory to the necessity of the stomata being open for passage of carbon dioxide. The system of conducting tissues in the leaf serves not only to remove manufactured food, but to bring water to the leaf from the root.

In discussing the biochemistry of photosynthesis, there is an excellent opportunity to review the earlier chemistry chapters and to relate their contents to the process of photosynthesis. Here again the student will meet ATP, atoms, molecules, and electrons. As Figure 15-9 (text page 298) summarizes, photosynthesis is seen to require light for only part of its series of reactions, the rest being capable of taking place without light. The magnitude of photosynthesis occurring on the surface of the earth is

discussed, and students can be led by open-ended discussion to the observation that more efficient photosynthesis could lead to increasing supplies of foodstuffs and other materials. From their knowledge of the photosynthetic process, the students are asked to speculate on ways in which its efficiency can be improved, and they are given information on some of the areas in which current work is proceeding toward this goal.

Within this chapter there are ample opportunities to stress thematic materials, such as complementarity of structure and function, homeostasis, adaptation, evolution, and the molecular nature of living processes.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 300)

1. Cells of the palisade and spongy layers of leaf tissue, together with the paired guard cells, contain chloroplasts.
2. Wavelengths of light in the blue, violet, orange, and red regions of the visible spectrum are absorbed by chloroplasts. This can be demonstrated experimentally by passing a beam of light through a solution of chlorophyll, then through a glass prism, and noting the wavelengths that are partially or completely absent—an indication that they have been absorbed by the chlorophyll solution.
3. Light in the green region of the spectrum is transmitted, along with most of the light in the yellow region, and small parts of the blue and red. This result is interpreted as demonstrating that green and yellow light, and small parts of the blue and red, are neither absorbed nor used extensively in the process of photosynthesis.
4. The carbon dioxide in the air enters the leaf through the stomata, dissolves in the watery layer covering the spongy and palisade cells, and is thus absorbed. As it is absorbed from the air spaces and used in photosynthesis, its concentration within the leaf drops, and it diffuses more rapidly from the surrounding atmosphere into the air spaces of the leaf.
5. The guard cells control the opening and closing of the stomata and, thus, the rate of diffusion of materials into and out of the air spaces within the leaf. On the leaf of a water lily, one would expect to find guard cells on the upper surface, as they would be of little adaptive value under the water.
6. Photosynthesis takes place in the illuminated guard cells and, as sugar accumulates in the guard cells, the relative concentration of water decreases. Water then diffuses from the adjacent epidermal cells into the guard cells, rendering them turgid. They then part like two sausages connected at both ends and form an opening through which air (containing carbon dioxide) can pass into the leaf. When the guard cells are not illuminated, the sugar content drops and the relative amount of water in the cells thus increases. Water then diffuses out of the guard cells into the surrounding epidermal cells, and the guard cells become less turgid. Their inner walls then move together until the stoma between them is closed. The diffusion of water into and out of the guard cells thus regulates diffusion of air and water vapor into and out of the air spaces within the leaf. The principles of diffusion here are the same as those outlined in Chapter 6.
7. When the stomata are closed little water is lost to the air from the leaves. When the stomata are open, however, water can diffuse readily out of the leaves. When there has been an excessive water loss and

the plant has begun to wilt, the stomata are closed by the diffusion of water out of the guard cells; further loss of water through the stomata is thus prevented, until the water supply is built up again by transport from the roots.

8. The veins of the leaf, containing xylem and phloem cells, allow water to be moved into the leaf from the root area through the xylem cells. Carbon dioxide passes through the stomata into the air spaces within the leaf, from which it diffuses into palisade and spongy cells. Light penetrates the surface cells of the leaf to activate the chlorophyll, and carbohydrates are manufactured (from the carbon dioxide and water supplies). The phloem cells of the leaf veins then move the manufactured carbohydrates from the leaf to the stem and roots where the carbohydrates are stored as starch.
9. The oxygen produced by photosynthesis comes from the water that is used, not from the carbon dioxide. This fact has been demonstrated experimentally by use of a radioactive isotope of oxygen in the water or the carbon dioxide supplied to a plant. For example, if the water used in photosynthesis contains O^{18} instead of the more usual O^{16}, a check of the oxygen given off by the plant will reveal the source of the oxygen.
10. In the light reactions of photosynthesis, the absorbed light energy causes high-energy electrons to be released from the chlorophyll molecules. Some of the energy is immediately used to change ADP to ATP, and the rest is used to split molecules of water, leading to formation of TPNH or other high-energy hydrogen compounds (containing hydrogen derived from the water). Chlorophyll thus provides the electrons (eventually returned to the chlorophyll molecule) whose energy is transferred partly to ATP and partly to TPNH.
11. In the dark reactions of photosynthesis, ATP and reduced TPN (TPNH) react with molecules of carbon dioxide to form water and glucose. Thus, part of the original energy of light that was captured in ATP and TPNH becomes locked up in the form of chemical energy in glucose molecules. Without the sources of energy and hydrogen (ATP and TPNH) provided by the light reactions, the dark reactions could not take place.

REFERENCES

Chapter 6 (page 242) of the *Teachers' Handbook* treats energy in light and will provide a reference for the teacher who wishes to review what is known of photosynthesis. (The Calvin and Bassham book listed below is another up-to-date reference.) Invitation to Enquiry No. 19 (page 113) in the *Teachers' Handbook* uses photosynthesis to treat serial causation, and Invitation No. 27 (page 148) introduces linearity and limiting factors by means of light intensity and photosynthesis.

Useful books:

Calvin, M., and J. A. Bassham. 1962. *The Photosynthesis of Carbon Compounds*. W. A. Benjamin, New York

Galston, A. W. 1961. *The Life of the Green Plant*. Prentice-Hall, Englewood Cliffs (N. J.)

Ray, P. M. 1963. *The Living Plant*. Holt, Rinehart and Winston, New York

Articles in journals:

Arnon, D. 1960. "The Role of Light in Photosynthesis." *Sci. Am.* 203 [5] 104

Lehninger, A. 1961. "How Cells Transform Energy." *Sci. Am.* 205 [3] 62

Rabinowitch, E. 1948. "Photosynthesis." *Sci. Am.* 179 [2] 25

FILMS

Multicellular Plants, Part III: *Leaves*, No. 3, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Chlorophyll*, No. 4, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Role of Green Plants*, No. 5, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Carbon Fourteen, 1953, (sd, b&w, 12 min), p or r, EBF

Leaves, 1936, (sd, b&w, 11 min), p or r, EBF

The Riddle of Photosynthesis, 1955, (sd, b&w, $12\frac{1}{2}$ min), p, Handel

Chapter 16 STEMS AND ROOTS—A STUDY OF COMPLEMENTARITY OF STRUCTURE AND FUNCTION

RATIONALE

In Chapter 15, the theme of complementarity of structure and function was presented but not emphasized in the discussion of the leaf. Chapter 16, in its treatment of the stem and the root, opens by stressing once again the importance of this theme.

The stem, as an organ of support and conduction, can be categorized as either herbaceous or woody. In either case, the upward conduction of water and solutes takes place through a system of cells known as tracheids and vessels. The downward conduction of sugars through the stem to the root is accomplished through the sieve tubes of the phloem.

The vascular cambium is studied as the region of growth in the stem and the root. Secondary phloem and xylem (including the annual rings of woody stems) are produced by multiplication and differentiation of cambium cells.

The root differs from the stem (in all but primitive plants) in its central location of xylem and phloem, and in its function of anchoring the plant and obtaining water and its contained solutes from the surrounding soil.

As in several earlier chapters, students encounter and study diffusion as they follow the path of water and solutes from the soil into the root. Diffusion alone does not account for transport, however. The concentration of ions in the root may be many times that in the surrounding soil, indicating forces at work that were not encountered in earlier examples of diffusion along a gradient from high to low concentration. In this case, materials are moved <u>against</u> a gradient with a requisite expenditure of energy, and with an oxygen requirement on the part of the root. Although

the term "active transport" is yet to be introduced by the textbook, this is an example of the process, and some teachers may wish to introduce the term at this point.

The upward movement of materials in plants takes place at a rate far beyond that expected by the force of atmospheric pressure alone. The ascent of water and solutes to heights beyond the limits of atmospheric pressure is related to transpirational pull upon the liquid in tubes of small diameter (tracheids and vessels), to whose walls water tends to adhere. In this case, the evaporation (transpiration) of water from the leaf can pull unbroken columns of water to heights that would be impossible in a simple physical system depending only upon capillarity and atmospheric pressure.

The movement of materials downward through the phloem of the stem depends on living tissues, for here again movement is occasionally against a gradient, requiring energy (which only living cells can provide). Students should see, at this point, that the energy required to move materials through the plant is derived from plant foods, produced by photosynthesis; thus, the ultimate source of energy so expended is the sun.

In general, plants store about 25 percent of the food they manufacture. This food becomes the source of supply for the heterotrophic organisms of the world. Thus, the storage of starch in the cortex of roots and stems constitutes the sole source of nutrients for the animal kingdom.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 316)

1. The stems of higher plants perform two major functions: (a) support for the leaves and other photosynthetic tissues of the shoot; and (b) transport of materials from leaves to roots and vice versa. The stems are adapted to these functions in several ways. In herbaceous stems, mechanical strength and support are provided partly by bundles of vascular tissue (and their "cap" cells) and partly by the turgidity of the stem cells. In woody stems, strength and support are provided by secondary growth of vascular tissue—the annual rings of xylem produced by the cambium layer. In both woody and herbaceous stems, vessels and tracheids carry water and dissolved solutes from root to leaf while the sieve tubes of the phloem carry dissolved sugars from the leaf to the root.
2. In this sense, herbaceous plants depend upon water to maintain cell turgor, a factor in the mechanical strength of stems and petioles.
3. Aquatic plants are buoyed up by water; their weight is not borne by the stem. It is not necessary for these plants to have firm, strong stems such as those that support land plants.
4. Xylem tissues consist of vessels and tracheids that conduct water and dissolved solutes from the root to the leaf. Phloem consists of sieve tubes and their associated companion cells; dissolved sugars move from leaf to root through the sieve tubes.
5. Both tracheids and vessels consist of series of dead cells that serve as conducting elements. Tracheids have permeable cellulose walls with periodic thin areas called "pits," through which materials can easily pass. Vessels are hollow and are joined together end to end to form an open pipelike structure through which materials freely move, in contrast to the situation in tracheids, where the materials must diffuse across the pits.

6. The cells of the sieve tubes of the phloem transport the dissolved sugars from leaf to root.
7. The rings of growth of woody plants can be interpreted as determining the age of the plant, for in temperate climates, the cambium forms cells of different sizes corresponding to the varying conditions during the growing season, resulting in the ringlike pattern. Each new ring of numerous layers of xylem cells serves to mark one year's growing season.
8. The root serves to anchor the plant, absorb water and soluble nutrients from the soil, and provide conducting tissues for distributing these substances to the tissues of the stem, or the shoot. The root contains a core of xylem tissue and phloem tissue that conducts materials, it has thin-walled root hairs that readily absorb water and nutrients from the soil, and as it grows it penetrates the soil more deeply or over a wider area, serving to anchor the plant.
9. Atmospheric pressure alone is sufficient to raise water to a height of 10.36 meters (at sea level), a height far less than that of many of our tall trees. Transpirational pull, which occurs as water evaporates from the leaf, better accounts for the rise of water in tall trees. Conditions for this rise are: (a) the water must be in tubes (dead cells) of small diameter, to whose walls the water will adhere; and (b) the column of water cannot be broken by gas bubbles. Under these conditions, as evaporation in the leaves occurs, water will be drawn upward from the roots through the stem and into the leaves.

REFERENCES

Useful books:

Carlquist, S. 1961. *Comparative Plant Anatomy*. Holt, Rinehart and Winston, New York

Crafts, A. S. 1961. *Translocation in Plants*. Holt, Rinehart and Winston, New York

Esau, K. 1953. *Plant Anatomy*. John Wiley & Sons, New York

Foster, A. S., and E. M. Gifford, Jr. 1959. *Comparative Morphology of Vascular Plants*. W. H. Freeman, San Francisco

Fuller, H. J., and A. B. Carothers. 1963. *The Plant World*, 4th ed. Holt, Rinehart and Winston, New York

Knobloch, I. W. 1963. *Selected Botanical Papers*. Prentice-Hall, Englewood Cliffs (N. J.)

Articles in journals:

Biddulph, S., and O. Biddulph. 1959. "The Circulatory System in Plants." *Sci. Am.* 200 [2] 44

Williams, S. 1953. "Wood Structure." *Sci. Am.* 188 [1] 64

FILMS

Multicellular Plants, Part III: *Roots*, No. 6, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Stems*, No. 7, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Root Development, 1951, (sd, b&w, 10 min), p or r, IIJW

Roots of Plants, 1957, (sd, b&w or c, 11 min), p or r, EBF

Chapter 17 REPRODUCTION AND DEVELOPMENT IN FLOWERING PLANTS

RATIONALE

This chapter ends the second subsection of Part II of the textbook. Chapters 12-16 have led the students through an evolutionary development from fungi and primitive plants to the highest evolved land plants, parts and functions of which were treated in Chapters 15 and 16, and now in Chapter 17.

The final topic in the coverage of the plant kingdom is reproduction and development in the flowering plants. Students have had numerous exposures to reproduction at the cellular level and in the various representative plants covered in the evolutionary plant story. Here are reviewed, in terms of flowering plants, the elements of asexual reproduction as evidenced by vegetative propagation, and the highly evolved means of sexual reproduction.

In order to understand reproduction in the flowering plants, students are first introduced to the structure of a generalized flower and then to the flower as a functional reproductive structure. A study of fertilization, the development of the seed, and subsequent growth and differentiation gives opportunity first to review mitosis and secondly to understand how cells become specialized in a multicellular organism. For the latter purpose, the development of the root and the shoot are used as examples.

Little attention has been paid by most textbooks to plant responses to the environment. Here the student is introduced to tropisms and the mechanisms of tropic responses through the historical development of the discovery of auxins and their mode of action. Bioassay as a technique for measuring the concentration of a substance is introduced and will later appear in both laboratory and text. Substances such as IAA and 2,4-D are used to exemplify the varying effects of growth substances—from promoted growth and development to abnormal growth and death—upon various kinds of plants. Practical applications of the use of these substances by man are discussed.

The concluding portion of the chapter summarizes some of the biological considerations of plant life and reintroduces interdependence among plants and animals, a theme that by being stressed at this point serves to introduce the detailed study of animals in Chapters 18-29.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 335)

1. a. Certain plants, such as bananas, some kinds of grapes, and navel oranges, must reproduce vegetatively if they are to reproduce at all, since they form either infertile seeds or no seeds at all. Vegetative reproduction is also a relatively efficient means of reproduction; it produces individuals without the necessity of fertilization and seed formation. Also, because vegetatively reproduced plants are genetically like the parent, there are no losses of new plants due to unfavorable genetic recombinations.

b. From man's point of view, vegetative propagation is advantageous because it introduces no new genetic recombinations; plants of proven quality can be used to produce large numbers of identical plants for commercial purposes.

2. The pollen tube digests its way through the tissues of the stigma, style, and ovary to the ovule, and thus forms a passageway along which sperms can pass to reach the egg and the polar nuclei.
3. One sperm unites with the egg to form a zygote, and the second sperm fertilizes the fusion nucleus to induce the formation of the endosperm tissue, in which foods are stored for subsequent use by the embryo.
4. A seed is the structure produced by the development of an ovule in a seed-bearing plant, after fertilization has taken place; included in the seed are an embryo plant, stored foods, and a seed coat. A fruit is the structure produced by the development of an ovary of a flowering plant, after fertilization has taken place; as a rule it contains seeds (although in some fruits, seeds are not produced).
5. Cross-pollination assures the greatest possible variety of offspring. Producing a variety of plants is an advantage, for some may be capable not only of living in the environment of the parent plants but of extending the range into environments to which the parent plants had not been well adapted. Two of the disadvantages of cross-pollination are: (a) the production of some plants that are less well adapted to the existing environment than the parent plants were; (b) the risk that cross-pollination may not take place efficiently in the population of plants, because of the absence of insects at the proper time, or the absence of sufficient wind, or other difficulties.
6. Observation of a young bean plant reveals the mitotic processes and differentiation of cells and tissues, whereby an increase in cell number is followed by an increase in the size and number of types of cells. The patterns of growth in the root and shoot can be observed—cell division near the tip, elongation of cells a bit removed from the tip, and differentiation of cells that are approaching their maximum elongation.
7. The ultimate source of energy for the growth and development of a young plant is solar energy, captured by photosynthesis and stored in the form of chemical energy in starches produced by the plant.
8. The vascular cambium is the thin layer of cells between the primary xylem and phloem of each strand or bundle of vascular tissue in the stem. The cambium cells retain their capacity to divide and produce new cells. It is the new cells so produced that differentiate into secondary xylem and phloem and cause an increase in the diameter of the stem—that is, growth.
9. Charles Darwin's controlled experiments on the growth of plants involved exposing seedlings in an otherwise dark room to a single, directional source of light. The tips of some seedlings were protected by tiny caps of tin foil; the tips of some of the other seedlings were removed rather than shaded. Subsequent observation showed that the tips were the regions that react to the light, causing curvature toward the light some distance below the tips.
10. F. W. Went used the technique of bioassay for measuring the relative amount of auxin. He allowed the active substance to diffuse from cut coleoptile tips into agar, and he demonstrated that the amount of auxin absorbed by the agar was proportional to the number of cut coleoptile

tips that had been placed on the agar. The actual bioassay consisted of measuring the degrees of curvature produced in decapitated coleoptiles by auxin from agar blocks that had been exposed to different numbers of cut coleoptile tips.

11. IAA is used to stimulate the formation of roots in cuttings that are difficult to propagate. NAA is used to retard sprouting of potatoes, as well as to help prevent the falling of fruits before they are fully developed. NAA is also used to accelerate the production of flowers and fruits. Gibberellins are used to stimulate stem elongation, and 2,4-D is used to kill unwanted plants (by inducing abnormal growth). Thus, auxin and other growth substances can be used to control patterns of growth and development and to eliminate unwanted plants.

REFERENCES

The *Teachers' Handbook* has two "Invitations to Enquiry" which will be of value in teaching this chapter. No. 14 (page 93) deals with auxins and plant movement and No. 30 (page 165) with light and auxin formation.

Useful books:

Allard, R. W. 1960. *Principles of Plant Breeding*. John Wiley & Sons, New York

Dana, W. 1963. *How to Know the Wild Flowers*. Dover, New York

Esau, K. 1960. *Anatomy of Seed Plants*. John Wiley & Sons, New York

Greulach, V. A., and J. E. Adams. 1962. *Plants: An Introduction to Modern Botany*. John Wiley & Sons, New York

Hillman, W. S. 1962. *The Physiology of Flowering*. Holt, Rinehart and Winston, New York

Poehlman, J. M. 1959. *Breeding Field Crops*. Holt, Rinehart and Winston, New York

Porter, C. L. 1960. *Taxonomy of Flowering Plants*. W. H. Freeman, San Francisco

Articles in journals:

Biale, J. B. 1954. "The Ripening of Fruit." *Sci. Am.* 190 [5] 40

Butler, W., and R. Downs. 1960. "Light and Plant Development." *Sci. Am.* 203 [6] 56

Salisbury, F. B. 1958. "The Flowering Process." *Sci. Am.* 198 [4] 108

_____ 1957. "Plant Growth Substances." *Sci. Am.* 196 [4] 125

Steward, F. 1963. "The Control of Growth in Plant Cells." *Sci. Am.* 209 [4] 104

FILMS

The Growth of Plants, 1962, (sd, b&w or c, 21 min), p or r, EBF

Angiosperms: Flowering Plants, 1962, (sd, b&w or c, 21 min), p or r, EBF

Seed Germination, 1961, (sd, b&w or c, 14 min), p or r, EBF

Multicellular Plants, Part III: *Seeds and Germination*, No. 2, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Development*, No. 8, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Regulation of Growth*, No. 9, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Flower Structure*, No. 10, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Multicellular Plants, Part III: *Flower Functions*, No. 11, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Diversity of Plants, Part VII: *Likenesses and Differences in Angiosperms*, No. 10, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Diversity of Plants, Part VII: *Life of the Angiosperm*, No. 11, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Diversity of Plants, Part VII: *Diversities and Similarities of Plants*, No. 12, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Flowers at Work, 1956, (sd, b&w or c, 11 min), p or r, EBF
Reproduction in Plants, 1958, (sd, b&w or c, 14 min), p or r, Coronet

Chapter 18 THE WORLD OF ANIMALS

RATIONALE

Earlier chapters have set the stage for the study of highly evolved heterotrophs; accordingly, this chapter introduces students to the animal kingdom. The distribution of animals is shown to be dependent upon the distribution of plants and upon the physical environment; a review of the distribution of organisms in the biosphere shows that life occurs in a fairly shallow zone over the planet Earth—a zone in which water, oxygen, and plants are available to animals as food sources, and carbon dioxide and certain organic compounds are available to the plants. Temperature, too, limits the distribution of organisms. Despite the millions of species of plants and animals on the earth today, few are found in the truly hostile environments of the globe.

The common features of plants and animals—cell structure, basic biochemistry, and energy sources—are discussed. The major difference between green plants and animals is that green plants are autotrophic, while animals are heterotrophic.

Here again, as earlier, the difficulties of trying to classify organisms arbitrarily as plants or animals are discussed. However, students are provided with a working definition of "animal"—a definition that will fail in some cases but work for most. A growing awareness of the concept of "animal" is left for development in subsequent chapters.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 342)

1. Life is most abundant where light, moderate temperatures, and supplies of necessary chemical substances are available. These conditions reach a peak in the moist tropical regions of the earth.
2. If man controls his environment, the process of natural selection of individuals best suited to survive is no longer as critical, for the environment can be modified for the survival of individuals who could not otherwise withstand the environmental rigors. In effect, the decreased degree of natural selection by the environment could prevent or modify environmentally directed courses of human evolution.
3. Plants and animals are alike in being composed of cells that contain nuclei, chromosomes, nucleoli mitochondria, Golgi bodies, ribosomes, and cell membranes. In both types of organisms, cell nuclei

divide by mitosis. In special circumstances, a monoploid number of chromosomes is produced by meiosis and restored to the diploid condition through the fusion of two gametes at fertilization. Cells of many plants and animals have the same enzymes. Both types of cells transfer energy from glucose to ATP in the process of respiration. Both use DPN, riboflavin, nucleotides, and cytochromes in this process. Both use the energy derived from respiration in the same ways—for growth, reproduction, movement, for responding to environmental changes, and so on. The significance of these similarities is that all living organisms have a basic structure and function that indicates a common ancestry.

4. Green plants and animals differ in that the green plants possess chlorophyll in chloroplasts, and are autotrophic, photosynthetic organisms. Their cells have stiff cell walls. Animals are heterotrophic, they do not have chlorophyll, and their cells do not have thick cell walls.

REFERENCES

Useful books:

Buffaloe, N. D. 1962. *Principles of Biology*. Prentice-Hall, Englewood Cliffs (N. J.)

Griffin, D. R. 1962. *Animal Structure and Function*. Holt, Rinehart and Winston, New York

Hardin, G. 1961. *Biology: Its Principles and Implications*. W. H. Freeman, San Francisco

Weisz, P. B. 1961. *Elements of Biology*. McGraw-Hill, New York

Article in journal:

Newell, N. D. 1963. "Crises in the History of Life." *Sci. Am*. 208 [2] 76

FILMS

Ecology, Part IX: *Plant and Animal Distribution*, No. 1, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Continuity of Life: *Characteristics of Plants and Animals*, 1954, (sd, b&w or c, 10 min), p or r, Indiana

The Eternal Cycle, 1954, (sd, b&w, 12½ min), p, Handel

Diversity of Animals, Part VIII: *Nature of Diversity*, No. 1, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 19 PARAMECIUM AND THE ANIMAL WAY OF LIFE

RATIONALE

In this chapter, a unicellular organism, *Paramecium*, is used to exemplify all the major living processes that occur in animals. The confusing details of specialization in multicellular organisms often obscure the basic nature of the essential processes that occur in animals; hence, the basic

animal pattern is established first for a one-celled organism, after which the more complex animals will be studied (in later chapters).

The animal is introduced as an organism completely dependent on the biochemical proficiencies of other organisms for its existence. The food-gathering way of life is dependent upon some sort of digestive mechanism (except in parasites) to break down the large molecules obtained from the environment, either intracellularly or extracellularly by hydrolytic reactions controlled by enzymes. The problems of movement, feeding, digestion, transport, assimilation, energy release, water removal, hydrostatic balance, coordination and behavior are all described for *Paramecium*.

Reproduction of *Paramecium* is both sexual and asexual. It is the first animal reproduction students will have studied in this course. Later it can be compared with and contrasted to reproduction in other animals. At this point it should be related to reproductive patterns in microorganisms and plants.

Coordination and behavior in *Paramecium* is of a relatively simple type; *Paramecium* population growth demonstrates some of the same principles studied earlier in populations of developing yeasts and bacteria. *Paramecium* is in competition with other protozoans. Its ability to withstand unfavorable environmental conditions, perhaps by forming cysts—although these have never been seen and identified—can be analogized to spore formation in microorganisms previously studied; whatever the exact method of survival, it enables *Paramecium* to compete successfully with more environmentally sensitive organisms.

At the end of the chapter, the essential processes of animal life are reviewed, and a question is raised as to whether *Paramecium* should be considered a single cell or an acellular organism.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 357)

1. Most animal cells require oxygen, water, salts, glucose, fatty acids, amino acids, and glycerol, as well as vitamins.
2. Animals can be regarded broadly as parasites because they depend upon other organisms for their organic molecules.
3. During digestion, either intracellular or extracellular, carbohydrates are hydrolyzed to glucose or other simple sugars, all proteins are hydrolyzed to mixtures of amino acids, and fats are hydrolyzed to fatty acids and glycerol. All these hydrolytic reactions are enzyme-controlled.
4. Food molecules that reach the cells by diffusion are used in one or more of three ways: (a) for the synthesis of new living material; (b) for the production of secretions, or (c) for the liberation of energy.
5. One-celled animals must carry on all life activities within the single cell of which they are composed. Multicellular animals develop cellular specializations, so that some cells become adapted for digestion, some for contraction, some for transmission of impulses, and others for other living processes. The problem may seem more complex for one-celled animals than for multicellular organisms, but the difficulties of diversification for one cell are more than balanced by the difficulties of coordination, supply, and excretion among many cells.
6. *Paramecium* obtains its food by sweeping food materials along the oral groove into the gullet, and then into a food vacuole, which is formed at the end of the gullet. Cilia lining the oral groove create the

currents that bring in the food. The larger food molecules are digested in food vacuoles that circulate through the body of the *Paramecium*.

7. Digested foods are distributed to all parts of the *Paramecium* by the flowing of the cytoplasm within the cell membrane, and to a lesser extent, by diffusion.
8. The energy of ATP is used for all the energy-requiring activities of the cell, just as in all higher organisms. The oxygen needed for energy release diffuses across the cell membrane into the cell from the pond water.
9. Carbon dioxide and water are the major wastes of carbohydrate and fat metabolism. Ammonia is a waste product of protein metabolism. Carbon dioxide and ammonia diffuse out through the cell membrane. Water is largely expelled by the contractile vacuoles.
10. Contractile vacuoles maintain water balance by pumping excess accumulated water out of the animal. Without such a hydrostatic structure, the cell would accumulate water until it burst.
11. Saltwater protozoans would not be expected to have contractile vacuoles because they are essentially isotonic with their saline environment; in other words, the relative concentration of solutes inside and outside the cell is similar, so that excesses of water do not diffuse into the cell.
12. Some evidences of a coordinating mechanism in *Paramecium* are its responses to a variety of stimuli and the fact that its cilia beat in a coordinated fashion to move it through the water.
13. *Paramecium* reproduces asexually by a process of cell division, involving the division of both nuclei.
14. As in all cases, sexual reproduction is significant in the introduction of genetic variation into new individuals. The long-term effect of sexual reproduction is to provide a variety of hereditary patterns from which the processes of natural selection will pick those most suited to the environment.
15. When a living food organism, such as yeast, is introduced into the environment of a population of *Paramecium*, the cycle of growth and decline of the *Paramecium* population follows that pattern established by the yeast population. When a predator of *Paramecium*, such as *Didinium*, is introduced, the entire *Paramecium* population may be wiped out. When *P. aurelia* is introduced into the environment of a population *P. caudatum*, the competitive advantage of *P. aurelia* causes natural selection to operate in its favor. The *P. aurelia* population increases, while the *P. caudatum* population declines and is eliminated from the culture.

REFERENCES

Useful books:

Dethier, V. G., and E. Stellar. 1961. *Animal Behavior*. Prentice-Hall, Englewood Cliffs (N. J.)

Jennings, H. 1962. *Behavior of the Lower Organisms*. Indiana University Press, Bloomington (Ind.)

Loewy, A. G., and P. Siekevitz. 1963. *Cell Structure and Function*. Holt, Rinehart and Winston, New York

MacKinnan, D., and R. Hawes. 1961. *An Introduction to the Study of Protozoa.* Oxford University Press, New York
Scheer, B. T. 1963. *Animal Physiology.* John Wiley & Sons, New York
Slobodkin, L. B. 1961. *Growth and Regulation of Animal Populations.* Holt, Rinehart and Winston, New York
Wichterman, R. 1952. *The Biology of Paramecium.* McGraw-Hill, New York

FILMS

Single-Celled Animals, 1962, (sd, b&w or c, 17 min), p or r, EBF
Microbiology, Part II: *Complex Microorganisms*, No. 3, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Microbiology, Part II: *Responses in Motile Forms*, No. 5, 1960, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Paramecium, 1950, (sd, b&w, 11 min), p or r, UW
Protozoa (One-Celled Animals), 1957, (sd, b&w or c, 11 min), p or r, EBF

Chapter 20 THE DIVERSITY AMONG ANIMALS—VARIATIONS ON A THEME

RATIONALE

In the previous chapter students have been introduced to the animal way of life as exemplified by a single kind of animal, *Paramecium.* In this chapter, the diversity of animal life is emphasized. The principles of classification by which biologists seek to establish degrees of relationship among animals are introduced.

The development of the species concept is handled from the historical viewpoint, beginning with John Ray and culminating in the binomial nomenclature of Linnaeus. The need for a common, worldwide system of naming organisms becomes evident when students are made conscious of the inadequacies and the sectional variability in use of common names.

After the establishment of the species concept, students are shown how species are classified into larger and larger groups, such as genus, family, order, class, phylum, and kingdom. From this, the idea emerges that biological classification is one way of systematizing biological knowledge. The more homologous structures and processes two organisms have in common, the more closely they are related. Analogy, as contrasted to homology, is a functional relationship without a basic similarity.

As biological classification has been commonly based upon superficial morphological evidence, it is necessary to point out in some detail that functional and biochemical homologies are also valid bases for classification, and that they may contribute increasingly to classification in the future, especially in establishing relationships where morphological differences tend to suggest few, if any, direct evolutionary links.

Ten phyla are characterized and will be the ones emphasized in the text and laboratory study of animals. It is important to avoid highly detailed morphological and systematic descriptions within the various phyla, for two reasons: (1) the general principles of classification within the ten phyla can be grasped readily, without the repetitive emphasis of long-term systematic studies; (2) the zoological classification scheme is at best in a state of transition, awaiting evidence that can help clarify hundreds of unresolved problems that have never been brought to the attention of students (thus, much of what would be learned in elaborated classification studies might have to be "unlearned" later).

Following the introduction to variety among animals, the chapter concludes with the observation that, despite the tremendous variety in the animal kingdom, all animals are much alike in basic ways: they must all obtain food, digest it (parasites excepted), transport the digested products, respire, excrete, reproduce, act in a coordinated way and, in general, carry out similar life patterns. The remaining chapters will deal with these various life problems, using specific examples from the phyla covered in this chapter.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 378-79)

1. The common names that are applied to animals are highly variable, frequently local, and inconsistent. Scientific names are applied by a set of established rules, are internationally recognized and constant, and each is used for only one species.
2. John Ray's concept of a species was that of a group of organisms consisting of the offspring of similar parents. Modern usage regards a species as a group of individuals that naturally interbreed with one another.
3. The term binomial nomenclature means a naming system employing two words. It was the system devised by Linnaeus in which every species is described by a generic and a trivial name, which together constitute its specific name. The use of binomial nomenclature has systematized and simplified naming by eliminating the use of more than one name for any species and by eliminating the use of the same name for more than one species.
4. Each successively larger category, from genus to family, family to order, order to class, etc., indicates broader, less detailed similarities that relate otherwise different groups of organisms to one another.
5. Two animals that belong to the same family have more features in common than two that belong to the same order but to different families. Two animals that belong to different orders but to the same class have still fewer features in common.
6. Homologous structures are those of common origin in evolution. The more homologous structures two animals have in common, the more closely they are related. Despite superficial changes, such as in the flipper of a seal or the wing of a bat, the basic structural pattern is maintained, indicating a common ancestor.
7. In that both a leg of a mammal and a leg of an insect are used for walking, they have similar functions, but they do not have a common structure or common evolutionary origin. Hence they are only anal-

ogous—that is, they are not related in the same fashion in which the leg of a man is related to that of a dog.

8. The basic coelenterate body plan is one with radial symmetry and a single opening into a digestive cavity. The body wall is a simple sac of two cell layers with noncellular material between them.
9. Flatworms have flattened, bilaterally symmetrical bodies consisting of three layers of cells. The nematodes have cylindrical rather than flattened bodies, and have no clearly marked head ends. Both groups of worms differ from the earthworms in not being segmented.

REFERENCES

Alston, R. E., *et.al.* 1963. *Biochemical Systematics.* Prentice-Hall, Englewood Cliffs (N. J.)

Barnes, R. D. 1963. *Invertebrate Zoology.* W. B. Saunders, Philadelphia

Goodey, T. (2nd ed. in preparation.) *Soil and Freshwater Nematodes.* John Wiley & Sons, New York

Guthrie, M. J., and J. M. Anderson. 1957. *General Zoology.* John Wiley & Sons, New York

Hanson, E. D. 1961. *Animal Diversity.* Prentice-Hall, Englewood Cliffs (N. J.)

Jaques, H. 1946. *Living Things, How to Know Them.* W. C. Brown, Dubuque (Iowa)

Savory, T. 1963. *Naming the Living World.* John Wiley & Sons, New York

Simpson, G. G. 1961. *Principles of Animal Taxonomy.* Columbia University Press, New York

FILMS

The First Many-Celled Animals: Sponges, 1962, (sd, b&w or c, 17 min), p or r, EBF

Stinging Celled Animals: Coelenterates, 1962, (sd, b&w or c, 17 min), p or r, EBF

Flatworms (Platyhelminthes), 1962, (sd, b&w or c, 16 min), p or r, EBF

Segmentation: The Annelid Worms, (sd, b&w,or c, 16 min), p or r, EBF

Adaptive Radiation—The Mollusks, (sd, b&w or c, 18 min), p or r, EBF

The Jointed-Legged Animals: Arthropods, 1962, (sd, b&w or c, 19 min), p or r, EBF

Echinoderms, Sea Stars and Their Relatives, 1961, (sd, b&w or c, 17 min), p or r, EBF

Earthworm, 1957, (sd, c, 11 min), p, Dowling

The Hydra, 1950, (sd, b&w, 11 min), p or r, UW

Grasshopper, 1955, (sd, b&w or c, 6 min), p or r, Coronet

Diversity of Animals, Part VIII: *Order in Diversity*, No. 2, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Animals, Part VIII: *Sponges and Coelenterates*, No. 3, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Animals, Part VIII: *Worms*, No. 4, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Animals, Part VIII: *Crustacea and Their Allies*, No. 5, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Animals, Part VIII: *Echinoderms, Bryozoans, and Rotifers*, No. 6, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Animals, Part VIII: *Insects and Spiders*, No. 8, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Diversity of Animals, Part VIII: *Mollusks, A Story of Adaptation*, No. 9, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 21 DIGESTION IN MULTICELLULAR ANIMALS

RATIONALE

While all animal requirements are similar, multicellular animals need special mechanisms for providing these requirements to the individual cells of their bodies. They have evolved such mechanisms by division of labor and specialization of function among their cells, leading to tissues, organs, and organ systems (first introduced in Chapter 8), including systems of transport within the body.

Because amino acids, simple sugars, vitamins, glycerol, and fatty acids are rare in the natural environment, animals almost never have these substances directly available to them. In addition, their availability from organic sources is complicated by the fact that they are usually incorporated into compounds whose molecules are too large to pass through cell membranes. Extracellular digestion is the process that changes the larger organic molecules to smaller kinds that can pass across cell membranes.

Digestion in representative animals is shown to be similar in such forms as the hydra and the planarian, and again in the earthworm and man. In the latter two, the digestive cavity is not simply a blind sac, as in the hydra and the planarian, but a continuous tube along which food is passed in one direction and is processed in various specialized parts of the digestive tract. Digestion in *Paramecium*, a topic of the last chapter, should be compared with that of the multicellular animals covered in this chapter.

Digestion in man is dealt with beginning in the oral cavity and in the stomach. Students are introduced to the topic of hormones by a discussion of gastrin. The hydrolysis of foods in the small intestine, and absorption in both the small and large intestines, complete the body's digestive process. The end products of digestion are small molecules that can pass through cell membranes readily and that can be used for energy and the making of the specific cell structure of the organism into which they have been taken.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 397)

1. The cells of a multicellular animal require the same material and expel the same wastes as does the single cell of a *Paramecium*. Cells of a multicellular animal differ from the cell of a *Paramecium*, however, in two main ways: first, they are too specialized to carry on within themselves all living processes as seen in *Paramecium*, and secondly, they are not close enough to the external environment to get food directly from it or be able to expel wastes directly into it.

2. All animals must obtain water, amino acids, simple sugars, fatty acids, glycerol, vitamins, oxygen, and other organic and inorganic substances from their environment.
3. Proteins, complex carbohydrates, and fats must be broken down into simpler, smaller molecules that can pass through cell membranes by diffusion.
4. In *Paramecium*, digestion is intracellular, as is most of the digestion in a hydra. Food vacuoles are found in the cells of both *Paramecium* and the hydra. The main difference is that in a hydra, a certain amount of extracellular digestion also takes place, unlike in *Paramecium*.
5. A tube-type of digestive tract with openings at both ends is more efficient than the single-opening, saclike system because it permits specialization of parts in a succession of digestive tasks as the food passes through the tube.
6. Chemical reactions proceed on the exposed surfaces of the material involved in the reactions. Chewing the food and breaking it up into smaller particles provides more surface for what subsequently is faster enzyme action.
7. The action of bile on fats does not consist of a chemical alteration of the fat molecules.
8. The salivary glands, found in the digestive systems of land vertebrates, would not be important to freshwater fish, as adequate water is already available for lubricating the food as it is passed quickly to the stomach in the fish. Further, any enzymes secreted into the oral cavity of the fish would be washed away in the water that passes over the gills (and thus out of the body) during respiration.
9. The hormones permit a rapid specific stimulation of secretion of digestive enzymes in the tract of man. Gastrin stimulates the secretion of gastric juice in the stomach, and secretin stimulates secretion of pancreatic juice.
10. The end products of digestion of carbohydrates are glucose and other simple sugars; of fats, fatty acids and glycerol; and of proteins, amino acids. All of these small molecules can pass through cell membranes, can be used for energy, and can be used by the cell to make its own specific structure.
11. The length of the small intestine, and the folds and villi of its inner lining, greatly increase its inner surface area and thus adapt it for absorption of the products of digestion. In addition, lymph and blood capillaries are available to carry away the soluble foods that are absorbed. Absorption is by means of diffusion, active transport, and a combination of the two.
12. The role of the large intestine in the digestive process is mainly the absorption of water. It also acts as a site of inhabitation by symbiotic bacteria that produce vitamins; the vitamins are absorbed along with the water that passes from the large intestine to the bloodstream.

REFERENCES

In the *Teachers' Handbook*, Invitation to Enquiry No. 22 (page 120) treats the control of the pancreas as an example of diverse causation. Invitation No. 23 (page 123) amplifies this topic.

Useful books:

Best, C. H., and N. B. Taylor. 1963. *The Human Body: Its Anatomy and Physiology*, 6th ed. Holt, Rinehart and Winston, New York

Griffin, D. R. 1962. *Animal Structure and Function*. Holt, Rinehart and Winston, New York

Rogers, T. A. 1961. *Elementary Human Physiology*. John Wiley & Sons, New York

Scheer, B. T. 1963. *Animal Physiology*. John Wiley & Sons, New York

Schmidt-Nielsen, K. 1960. *Animal Physiology*. Prentice-Hall, Englewood Cliffs (N. J.)

Youmans, W. 1962. *Human Physiology*, 2nd ed. Macmillan, New York

FILMS

The Multicellular Animal, Part IV: *Chemical Machinery*, No. 5, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Digestion (Mechanical), 1939, (sd, b&w or c, 17 min), p or r, UW

Digestion (Chemical), 1949, (sd, b&w or c, 19 min), p or r, UW

Digestion of Foods, 1938, (sd, b&w, 11 min), p or r, EBF

Human Digestion, (sd, b&w, 10 min), p or r, Contemporary

Human Body: Digestive System, 1958, (sd, b&w or c, 13 min), p or r, Coronet

Chapter 22 TRANSPORTATION WITHIN MULTICELLULAR ANIMALS

RATIONALE

No animal or animal cell large enough to be seen easily by the unaided eye can exist with diffusion as its sole means of transporting molecules. Therefore, even a form such as *Paramecium* will have materials transported by the movement of the cytoplasm within the cell. In the simpler multicellular animals, such as hydra, the amino acids, glycerol, and fatty acids that are made available in the digestive cavity are absorbed by the cells lining it. Cells of the outer layers depend entirely on the inner cells for their organic food nutrients. Even in such a simple form as hydra, however, the beating of flagella serves to circulate fluid within the digestive cavity.

The planarian is about as large as an animal seems to get without a general transport system, but even here there are modifications of the digestive system and special cells to carry liquid waste to the outside.

In the earthworm, the student sees the first example of a closed circulatory system with capillaries in which exchanges are made between the blood and the surrounding tissues. The closed circulatory system of the earthworm contrasts with the condition in arthropods in general, and in the grasshopper, which is a specific example of an animal with an open circulatory system (the blood moves back to the heart through spaces in the body). The circulatory system of man is like that of an earthworm in being closed. A definite heart, which pumps blood in two circuits, a pul-

monary and a systemic one, and arteries, capillaries and veins are the essential organs of man's circulatory system. This system is charged with transporting all foods, wastes, gases, and other materials through the human body. The fluid that is pumped, the blood, consists of plasma and cells, with most of the dissolved components carried in the plasma, and the oxygen and carbon dioxide carried principally by the red blood cells. White blood cells protect the body against bacteria, and the platelets are concerned with the clotting of blood. Because of the escape of liquid from the blood vascular system, a second system, noncirculatory in nature, collects the fluid as lymph and returns it to the circulatory system. This lymphatic system also acts to filter out harmful substances by means of its lymph nodes.

Students are quite likely to take the circulation of blood as a long-known and established fact, but a review of the work of William Harvey and Marcello Malphigi will help them to understand that blood circulation has been known for only about 300 years. Even then, its original demonstration by Harvey was quite incomplete. Harvey's theory of circulation awaited the development of the microscope before it could be proved.

From this chapter, students should develop an understanding that a transport system is necessary and is present in all complex multicellular animals. With minor variations, the system can be delineated as having some sort of pumping mechanism (heart), vessels for the transporting of liquid (arteries and/or veins, and capillaries), and a circulating fluid (the blood).

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 411)

1. Since diffusion depends upon molecular movement, it is extremely slow and is therefore effective as the principal transport mechanism only in microscopic forms or relatively small multicellular animals.
2. A simple and complete transport system would consist of a series of interconnecting tubes, some with thin walls and some of which could pulsate and serve as pumps to move the contained circulating fluid (blood).
3. Plasma filters through the capillary walls of the blood vascular system, leaving the blood cells and most of the proteins behind. This plasma filtrate constitutes the tissue fluid that bathes the body cells.
4. An open circulatory system, such as that of a grasshopper, consists of a heart and some major vessels leading from it. There are no capillaries or veins, however; the blood drains back to the heart through body spaces. In a closed system the entire circuit of the blood is within vessels (arteries, veins, and capillaries), with an exchange of material between the blood vascular system and the body cells occurring in the region of the capillaries. A closed system is more effective because the contained fluid moves more rapidly from heart to tissues and back, thus transporting materials at a faster rate than in an open circulatory system.
5. Transport systems function to carry digested foods, wastes, oxygen, carbon dioxide, hormones, vitamins and, indeed, all of the materials transported through the body.
6. Harvey studied hearts of many animals and determined that the heart was actually a pump. He postulated and demonstrated that blood moved

away from the heart in arteries and returned to it in veins. He noticed especially the one-way path of blood in veins due to the presence of valves. He thus approached the problem of circulation by experiment and observation.

7. Harvey never saw the connections between arteries and veins. Even though he knew such vessels must exist he could not demonstrate the presence of capillaries. This was left to Malphigi and his observations with the aid of a microscope.
8. As materials must diffuse in and out of the circulatory system, the large surface area provided by the capillaries makes possible more rapid exchange than could occur through a smaller area. Of equal importance is the fact that capillaries are so numerous that every cell in the body is near one, or several.
9. The plasma proteins help maintain the diffusion pressure of the blood, they aid in clotting, and they include the antibodies that help combat disease organisms.
10. Blood plasma contains: (a) wastes, removed from all body cells; (b) hormones (from the endocrine glands), that help regulate growth, reproduction, and general metabolism; (c) proteins, whose function is explained in the answer to Question 9; and (d) digested foods, absorbed from the intestines in the form of amino acids, simple sugars, or fats, and used either as energy sources or for the manufacture of more complex molecules. Some (in fact, most) of the carbon dioxide produced as a by-product of cellular metabolism is also found in the plasma.
11. Red blood cells carry oxygen and some carbon dioxide, white blood cells fight bacteria, and platelets are concerned with the clotting of the blood.
12. The lymph is that part of the plasma which diffuses out of the capillaries into the spaces between body cells. Both lymph and plasma are without blood cells; lymph also does not contain the plasma proteins. The significant point is that neither blood cells nor plasma proteins diffuse out of the bloodstream.

REFERENCES

Useful books:

Abramson, D. I. (ed.), 1962. *Blood Vessels and Lymphatics*. Academic Press, New York

Best, C. H., and N. B. Taylor. 1963. *The Human Body: Its Anatomy and Physiology*, 6th ed. Holt, Rinehart and Winston, New York

Gray, C. H., and A. L. Bacharach (eds.), 1961. *Hormones in Blood*. Academic Press, New York

Kabat, E. 1956. *Blood Group Substances: Their Chemistry and Immunochemistry*. Academic Press, New York

King, B. G., and M. J. Showers. 1963. *Human Anatomy and Physiology*, 5th ed. Saunders, Philadelphia

Luisada, A. 1962. *Cardiovascular Functions*. McGraw Hill, New York

Moulton, F. R., and J. Schifferes (eds.), 1960. *The Autobiography of Science*, 2nd ed. Doubleday, New York

Peeters, H. (ed.), 1962. *Protides of the Biological Fluids: Colloquia*, 10th ed. American Elsevier, New York

Tullis, J. 1953. *Blood Cells and Plasma Proteins: Their State in Nature.* Academic Press, New York
Youmans, W. B. 1962. *Human Physiology*, 2nd ed. Macmillan, New York

FILMS

The Blood, 1961, (sd, b&w or c, 16 min), p or r, EBF
The Multicellular Animal, Part IV: *Circulation*, No. 2, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Circulation, 1954, (sd, c, 17 min), p or r, UW
Heart and Circulation, 1937, (sd, b&w, 10 min), p or r, EBF
Work of the Blood, 1957, (sd, b&w or c, 14 min), p or r, EBF

Chapter 23 RESPIRATION IN MULTICELLULAR ANIMALS

RATIONALE

Respiration is a chemical process whereby glucose and some other substances are broken down to carbon dioxide and water, with the liberation of energy that may be stored as ATP. In addition to being expressed chemically, the term "respiration" applies to all the events concerned in getting oxygen to cells and in disposing of carbon dioxide. Respiration includes breathing, but breathing is not synonymous with respiration. Breathing is a term reserved for those events concerned with pumping air in and out of respiratory organs (lungs or tracheal tubes). Thus, a *Paramecium* or an earthworm may respire, but it does not breathe. Similarly, when one says that a frog "breathes" through his skin, this is a misnomer. Oxygen is diffusing through a moist membrane, the skin. The breathing is done only in relation to the lung of the frog.

The problems of respiration are somewhat similar to those encountered in digestion. In forms in which there is extracellular digestion, the small food molecules simply diffuse across cell membranes. Similarly, oxygen and carbon dioxide diffuse across the cell membrane of: (1) protozoans such as *Paramecium*, and (2) each cell in hydras and planarians. However, just as specialized digestive and transport structures are found in multicellular animals, so we find specialized respiratory devices in the multicellular terrestrial animals. In the earthworm, the skin acts as the respiratory organ, but this is possible only because of the development of the circulatory system to the point where there is a very extensive capillary bed beneath the surface of the skin. In the grasshopper, the circulatory system is of little consequence in respiration, for the tracheal tubes, which ramify throughout the arthropod body, carry the oxygen to the individual cells and remove carbon dioxide.

The essentials for a respiratory system are well exemplified in man, where large, thin-walled moist surfaces (the lungs) absorb oxygen from the inhaled air and release carbon dioxide from vascular tissues into the exhaled air. The structures concerned with breathing in man are dis-

cussed, and the complex mechanism whereby air is forced into and out of the lungs is described in some detail.

It is obvious that in man the respiratory organs themselves are not sufficient to provide oxygen to reach individual cells and, therefore, respiration requires not only the elaborate breathing mechanism, but the circulatory system as well. In the previous chapter the red blood cells were discussed. Here, their oxygen-containing pigment (hemoglobin) is described; students learn that hemoglobin is combined with oxygen in areas of high oxygen tension, and releases the oxygen in areas of low oxygen concentration. Carbon dioxide is carried mostly as a bicarbonate ion in the plasma; only a part of it combines with hemoglobin. In considering the chemical reactions that account for the transport of oxygen and carbon dioxide, students come to appreciate that neither hemoglobin in its oxygen-carrying capacity, nor the water involved with the bicarbonate ion, are ever consumed, but simply used over and over again.

At this point a review is in order so that the student does not think of the body as so many isolated and unconnected systems, a disjunct idea that frequently occurs when digestion, transportation, and respiration are studied in isolation from one another. The concluding remarks of this chapter focus the student's attention on the interrelationships between the circulatory system, the respiratory system, and the digestive system, for no one of them will exist and operate effectively independently of the others.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 420)

1. Gills are effective respiratory organs because they are moist, have a large surface area and a rich blood supply, and are in contact with water that contains oxygen.
2. In that both tracheal tubes and lungs are internal, their moist surfaces lose relatively little water by evaporation to the outside of the body; in this sense, they are advantageous respiratory structures in terrestrial forms. Both have large surface areas exposed to the air, with its oxygen supply. In addition, the lungs have a rich blood supply.
3. In complex animals, the circulatory system serves to take oxygen from the lungs (or other respiratory organs) to the cells, and to return carbon dioxide from the cells to the lungs. Without this transport mechanism, the animals could not properly respire.
4. The special respiratory molecules, such as hemoglobin, increase the oxygen-carrying capacity of the blood to from 13 to 50 times as much as could be carried by water without hemoglobin.
5. The hemoglobin molecules of blood have a great affinity for oxygen. They form a loose chemical combination with it, giving it up readily to oxygen-deficient cells. Upon their return to the respiratory organs, they pick up additional oxygen. One of their chief advantages is that they are not used up in this process.
6. Most of the carbon dioxide carried in the blood is in the form of bicarbonate ions in the plasma. The remainder is carried by the red blood cells, either as bicarbonate ions or combined with hemoglobin.
7. Respiration in the tissues involves an oxygen requirement and a carbon dioxide release. In pulmonary respiration, the blood gives up the carbon dioxide and absorbs oxygen.

8. At high altitudes, where the partial pressure of oxygen is low, breathing is more rapid in an attempt to bring more oxygen into the lungs. However, since the concentration of oxygen is relatively low, the proportion of hemoglobin that forms oxyhemoglobin in the lungs is less than at sea level, and therefore, the cells do not receive as much oxygen as they need.

REFERENCES

Invitation to Enquiry No. 26 (page 141) of the *Teachers' Handbook* deals with oxygen and carbon dioxide in respiration and may be used with this chapter.

Useful books:

Griffin, D. R. 1962. *Animal Structure and Function.* Holt, Rinehart and Winston, New York

Grodins, F. S. 1963. *Control Theory and Biological Systems.* Columbia University Press, New York

Ingram, V. 1963. *The Hemoglobins in Genetics and Evolution.* Columbia University Press, New York

Laverack, M. 1962. *The Physiology of Earthworms.* Pergamon, New York

Macfarlane, R. G., and A. H. T. Robb-Smith (eds.), 1961. *Functions of the Blood.* Academic Press, New York

Scheer, B. T. 1963. *Animal Physiology.* John Wiley & Sons, New York

Article in journal:

Zweifach, B. W. 1959. "The Microcirculation of the Blood." *Sci. Am.* 200 [1] 54

FILMS

Mechanisms of Breathing, 1954, (sd, b&w, 11 min), p or r, EBF

The Nose (Structure and Function), 1954, (sd, b&w or c, 11 min), p or r, EBF

Chapter 24 EXCRETION IN MULTICELLULAR ANIMALS

RATIONALE

Despite the considerable numbers of chemical reactions that occur in cells, few of these result in waste products. The chief waste products of cellular metabolism are carbon dioxide, water, and nitrogen-containing compounds. Their removal from the cells and from the body constitutes the function of excretion. Because the removal of carbon dioxide has been considered in Chapter 23, as a part of the process of respiration, Chapter 24 will consider only the removal of wastes other than carbon dioxide.

In a protozoan such as *Paramecium*, carbon dioxide and ammonia diffuse out through the cell membrane, and the contractile vacuoles pump out excess water. Diffusion is likewise sufficient to handle the carbon dioxide

and nitrogenous wastes of the cells of a hydra, while an expenditure of energy is necessary to rid the cells of water. Movement of material against a gradient is spoken of as active transport, and the active transport of water from the cells of a hydra requires energy. (This is also true of the contractile vacuoles in *Paramecium*.)

In the planarian, diffusion still accounts for the removal of carbon dioxide and nitrogenous wastes, but a special system of flame cells and tubes removes excess water. Again an expenditure of energy is necessary for the latter.

In the terrestrial earthworm, there are not only specialized waste-absorbing cells, which ultimately deposit their wastes as pigment in the skin, but also a pair of excretory tubes for nearly every segment of the body. The excretory tubes carry wastes to the outside of the body.

In the grasshopper, wastes are passed from the body through Malpighian tubules into the digestive canal, and thence to the outside. The type of excretory product, whether it be ammonia, urea, or uric acid, is dependent upon the amount of water available to the animal. Ammonia is highly toxic; it can be the nitrogenous waste product only in those animals that have great supplies of fresh water available to them (for example, *Paramecium*, hydras, planarians, and to a lesser extent, earthworms). Urea is less toxic and is excreted by those animals that have a moderate supply of water available to them (man, for example). Uric acid requires the least amount of water and is least toxic. It is the chief nitrogenous waste product in insects and birds.

For a consideration of excretion in man, it is helpful to review the chemistry of Chapter 5—at least the parts dealing with proteins. The physiology of excretion provides an excellent opportunity to impress upon students a practical application of this chemistry. The ornithine cycle, as a mechanism of converting highly toxic ammonia into relatively nontoxic urea, exemplifies anew the cyclical nature of many biological processes. (You may wish to compare it to the transport of oxygen by hemoglobin, as noted in Chapter 23.) The human excretory system is considered in some detail, and its parts are related to the overall process of excretion. The kidney offers a fine example of homeostatic control of the internal environment by a combination of the processes of filtration, diffusion, reabsorption, and active transport.

The problem of maintaining a constant internal environment involves the digestive, respiratory, excretory, and transport systems. This balance is maintained within relatively close tolerances, for even minor variations may lead to extreme disruption of body metabolism. In the chapter summary, text Figure 28-8 shows these interrelationships and gives an opportunity to pose the question of how this interrelated group of activities is coordinated, thus providing a transition to the coverage of coordination in the following chapter.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 430)

1. The important waste substances produced by the metabolic activity of complex animals are carbon dioxide, water, and nitrogen-containing compounds such as ammonia, urea, and uric acid.
2. The circulatory system picks up the waste products of cellular metabolism and carries them to the kidneys (or other excretory organs), where they are selectively removed from the bloodstream as a part

of the homeostatic maintenance of a constant internal environment. If there were no excretory organs, there would be no mechanism to remove waste products from the blood; conversely, without the circulatory system, the excretory organs would not be provided with the waste products that they excrete.

3. Glucose is reabsorbed from the tubule of the nephron and restored to the blood, even though its concentration in the blood is higher than that in the tubule. Simple diffusion alone cannot account for this movement <u>against</u> a concentration gradient; active transport, which involves the expenditure of energy, must be involved.
4. The kidneys remove from the blood those substances, except CO_2, that are in excess concentration, thus, along with the lungs, keeping the composition of the blood constant.
5. The cells of a hydra are in direct contact with the external environment, so that simple diffusion can take care of its excretory needs. The cells of the planarian, however, are not all in contact with the external environment; an additional internal system is necessary to remove wastes, principally water.
6. All excretory structures have the same functional aspect in common—that is, they remove from the internal environment of the body the excess by-products of metabolism that would interfere with the normal chemical activities of the cells. Because of their selective activity in removing waste products, they regulate the level of these substances in the organism and, thus, contribute to the internal maintenance of homeostasis.

REFERENCES

Useful books:

Adolph, E. 1962. *The Development of Homeostasis*. Academic Press, New York

Bourne, G. H. 1962. *Division of Labor in Cells*. Academic Press, New York

Easton, D. M. 1963. *Mechanisms of Body Functions*. Prentice-Hall, Englewood Cliffs (N. J.)

Harris, E. 1960. *Transport and Accumulation in Biological Systems*, 2nd ed. Academic Press, New York

Articles in journals:

Merrill, J. P. 1961. "The Artificial Kidney." *Sci. Am.* 205 [1] 56

Salisbury, B. F. 1954. "Artificial Internal Organs." *Sci. Am.* 191 [2] 24

Smith, H. 1953. "The Kidney." *Sci. Am.* 189 [6] 40

FILMS

The Multicellular Animal, Part IV: *Excretion*, No. 6, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Elimination, 1954, (sd, b&w, 13 min), p or r, UW

The Human Body: *Excretory System*, 1960, (sd, b&w or c, 13 min), p or r, Coronet

Kidneys, Ureters and Bladder, Their Structure and Function, 1947, (sd, b&w, 10 min), p, Bray

The Work of the Kidneys, 1940, (sd, b&w, 11 min), p or r. EBF

Chapter 25 COORDINATION IN MULTICELLULAR ANIMALS

RATIONALE

Division of labor among cells in multicellular animals leads to specialization, and the specialized cells, in turn, become dependent one upon another. With the advent of dependent cells, coordination is a necessity, for no organism could long exist with one or more groups of specialized cells carrying on their activities completely independent of the cells of the rest of the body. The ultimate purpose of coordination is survival, by: (1) maintaining normal homeostatic conditions for the life of the cells; and (2) responding to the surrounding environment in such a way as to make further homeostatic control even more probable.

A simple coordinating system can exist with only three parts: a coordinator, a way for information to pass from the parts of the organism to the coordinator, and a way for information to pass back from the coordinator to the various parts of the organism. These interrelationships of transfer of information to and from a coordinator are admirably demonstrated in breathing, which is used as an example of a process that involves coordination of cellular metabolism, the circulatory system, the muscular and skeletal systems, and the respiratory system.

All organisms have some kind of coordinating mechanism; even the single-celled *Paramecium* responds to its environment by coordinated movements of its cilia. In the majority of multicellular animals, coordinating systems are of two kinds, the nervous system and the endocrine system.

In the nervous system, stimuli are received by receptors and are transmitted as nerve impulses, passing along neurons until they reach effectors, which respond to the nerve impulses by: (1) contracting, if the effector is a muscle; or (2) secreting, or ceasing to secrete, if the effector is a gland. As the neurons in a neuron network or system do not fasten to one another, there is a slight gap between each one and its neighbor. This gap is called a "synapse."

The nervous system of a hydra is of a net-type, controlling the contraction of the animal. In a planarian there is a beginning of centralization, a concentration of neurons that can be called a brain, two main nerves (bundles of neurons) running the length of the body, and numerous lateral nerves. Sensory neurons carry nerve impulses from receptors to the central nervous system; motor neurons carry the nerve impulses from the central nervous system to the effectors. The nervous system of man is an elaboration of that seen in the planarian, with a wider variety of receptors, and with a brain and spinal cord that serve as coordinating centers between the sensory and motor neurons.

The relationship between the nervous system and the endocrine system is developed through the work of Loewi on the hearts of frogs, leading to the discovery that acetylcholine and adrenaline are necessary parts of the functioning nervous system and are not confined exclusively to the endocrine system.

While the nervous system acts on <u>specific</u> muscles or glands, and acts very rapidly, the hormones secreted by the endocrine system may have a

more diffuse or general effect, and act somewhat more slowly (because they are distributed by the bloodstream).

The endocrine glands of man are introduced, but are not themselves the main theme of the endocrine section. The story of diabetes mellitus and the discovery of it as an endocrine deficiency disease is developed as a story in scientific experimentation and observation; the importance of animal experimentation as demonstrated by th work of Von Mering and Minkowski, and the work of Banting and Best, is the point to be emphasized. Without this animal experimentation we might still, today, be without knowledge (of the cause of diabetes mellitus) that has saved hundreds of thousands of lives.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 448)

1. Division of labor leads to cellular specialization, and hence, to the necessity of coordinating the functioning of all the parts as the functioning of the whole.
2. In that carbon dioxide is a chemical substance traveling in the bloodstream and influencing the breathing center of the brain, it might be considered a hormone. However, it is not a glandular secretion but, rather, a waste product of general cell metabolism.
3. A lowered oxygen content of the blood, coupled with an increased carbon dioxide content due to cellular activity, influences the nervous system through the breathing center, which in turn causes acceleration of the rate of breathing in an attempt to get more oxygen into the blood. This interrelationship between cellular activity, the circulatory system, the nervous system, and, ultimately, the muscular and skeletal systems is an example of coordination of specialized body parts.
4. The breathing center detects the concentration of carbon dioxide in the blood and controls the rate and depth of breathing by stimulating the nerves that lead to the diaphragm and the rib muscles.
5. The nervous system of a hydra is in the form of a network with no central mass of neurons. There are no definite pathways for nerve impulses, and there are few specialized receptors. In a planarian there is a concentration of neurons that may be called a brain, which serves as a central coordinator. In addition, there are two longitudinal nerves, consisting of sensory and motor neurons, and numerous lateral nerves. There are a variety of receptors in the body of the planarian.
6. The neuron is generally long and thin, somewhat like an electrical wire. (However, its mechanism for transmitting impulses is not exactly analogous to the wire's transmission of electricity.)
7. The work of Loewi on the hearts of frogs first demonstrated the secretion of chemicals (acetylcholine and adrenaline) by nerve endings. Subsequent work has related this phenomena to tissues and organs of the body other than the heart.
8. The cerebrum is the seat of man's superior intelligence; specific areas of it are associated with such functions as movement and reception of information (impulses) from the sense organs. The cerebrum is further concerned with originating impulses that are sent out to the various parts of the body.
9. The principal thyroid hormone, thyroxin, regulates the general rate of metabolism of the body.

10. The pituitary secretes a hormone that affects the secretion of thyroxin by the thyroid, and thus, in part, controls the action of the thyroid glands.
11. The suspected gland could be removed from the body, and the results of this removal noted. If it had secreted an essential hormone, a metabolic disfunction should occur. As a check on the disfunction, the gland could be reimplanted, or its hormone injected, following which the animal should be normal again, at least temporarily.
12. Hormones from the thyroid gland, the thymus gland, and the pituitary gland serve to control and regulate body growth. However, malfunctions of any of the endocrine glands may lead to growth abnormality.
13. The regulation of glucose is complex. Several endocrine glands are involved—principally, the islets of Langerhans, the pituitary, and the adrenals.
14. The hormones of the adrenal glands influence the concentration of blood salts and the way in which glucose is used in the body. The adrenal medulla controls the rate of breathing and heartbeat and increases the concentration of glucose in the blood; it prepares the body for emergency situations. The parathyroid hormones control calcium metabolism in the body.

REFERENCES

In the *Teachers' Handbook*, "Invitations to Enquiry," Nos. 15, 17, 21, 22, 23, 24, 25, and 44 use hormonal examples as illustrations of "Enquiry" topics.

Useful books:

Euler, U. S. Von, and H. Heller (eds.), 1963. *Comparative Endocrinology*, two volumes. Academic Press, New York

Gardner, E. 1963. *Fundamentals of Neurology*, 4th ed. Saunders, Philadelphia

Gorbman, A., and H. Bern. 1962. *Textbook of Comparative Endocrinology*. John Wiley & Sons, New York

Wells, M. 1962. *Brain and Behavior in Cephalopoda*. Stanford University Press, Stanford (Calif.)

Wooldridge, D. 1963. *The Machinery of the Brain*. McGraw-Hill, New York

Articles in journals:

Brazier, M. 1962. "The Analysis of Brain Waves." *Sci. Am.* 206 [6] 142

Burnet, M. 1962. "The Thymus Gland." *Sci. Am.* 207 [5] 50

Gerard, R. 1953. "What is Memory?" *Sci. Am.* 189 [3] 118

Gray, G. 1950. "Cortisone and ACTH." *Sci. Am.* 182 [3] 30

_____ 1948. "The Great Ravelled Knot." *Sci. Am.* 179 [4] 26

_____ 1957. "The Organizer." *Sci. Am.* 197 [5] 79

Olds, J. 1956. "Pleasure Centers in the Brain." *Sci. Am.* 195 [4] 105

Rasmussen, H. 1961. "The Parathyroid Hormone." *Sci. Am.* 204 [4] 56

Snider, R. S. 1958. "The Cerebellum." *Sci. Am.* 199 [2] 84

Sperry, R. 1959. "The Growth of Nerve Circuits." *Sci. Am.* 201 [5] 68

Walter, W. G. 1954. "The Electrical Activity of the Brain." *Sci. Am.* 190 [6] 54

Zuckerman, S. 1957. "Hormones." *Sci. Am.* 196 [3] 77

FILMS

Fundamentals of the Nervous System, 1961, (sd, b&w or c, 17 min), p or r, EBF

Endocrine Glands, 1939, (sd, b&w, 11 min), p or r, EBF

Human Brain, 1955, (sd, b&w, 11 min), p or r, EBF

The Principles of Endocrine Activity, 1960, (sd, b&w or c, 16 min), p or r, Indiana

The Multicellular Animal, Part IV: *Hormones*, No. 7, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

The Multicellular Animal, Part IV: *The Nervous System*, No. 9, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

The Multicellular Animal, Part IV: *The Senses*, No. 10, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

The Multicellular Animal, Part IV: *The Animal and the Environment*, No. 12, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 26 ANIMAL SUPPORT AND LOCOMOTION

RATIONALE

While some animals are sessile, as most plants are, by far the majority of animals are mobile. Mobility seems to be a heterotroph property, primarily because of the necessity of the heterotroph to search for its food—a situation unlike that of a sessile plant, which can manufacture its food without the necessity of locomotion.

Chapter 26 is essentially a chapter on locomotion, involving the skeletal and muscular systems of multicellular animals. Coordinated with locomotion is body form. Sessile animals are those that show relatively poor locomotor ability and tend to be radially symmetrical—or otherwise to exhibit symmetry other than bilateral symmetry, which is the type found in rapidly moving animals.

Protozoa exhibit several types of locomotion involving flagella, pseudopodia, and cilia. These locomotor structures are coordinated within the animal and so provide directional movement. Some coelenterates, such as jellyfish, move by a type of jet propulsion. Some echinoderms have a water vascular system that moves the tube feet. Planarians glide on cilia, as waves of muscle contraction pass along the body, and earthworms show an accordionlike type of locomotion, based upon alternate contractions of longitudinal and circular muscle. However, none of these organisms is a rapid mover, because all of them, even though they have locomotor structures, lack appendages. Rapidly moving invertebrates, such as the grasshopper, have an exoskeleton to which the muscles fasten; the vertebrates, on the other hand, typically have an endoskeleton.

The type of muscle that moves the skeletal parts of the body is termed skeletal muscle. (Other types of muscle which may be considered are cardiac and smooth muscle, but they play no part in the locomotor story here developed.) As a muscle works only by contracting, a pair of muscles is

required to produce an action and reaction, such as flexion and extension. Contractility seems to be a basic attribute of cytoplasm, and skeletal muscle is composed of highly specialized contractile proteins, the two most common being myosin and actin. The energy for contraction of skeletal muscle comes from ATP; another energy-rich phosphate compound, creatine phosphate, is involved in converting ADP to ATP. A glycogen-glucose-lactic acid cycle also is involved in muscle cell metabolism and provides another of the textbook's examples of internal regulation, emphasizing the theme of homeostasis.

The advantage of an exoskeleton is primarily the advantage of a suit of armor, external protection. Usually the exoskeleton must be shed if the animal is to grow. An internal skeleton, however—one that is itself capable of growth—enables an animal to increase greatly in size, as evidenced by whales in the ocean and elephants on land. Whether we are dealing with endoskeletons or exoskeletons, however, the structure is important in locomotion and support, and in protecting internal parts of the animal. The endoskeleton is a living part of the organism, in which, in man, red blood cells are produced, fat is stored, and calcium is deposited or withdrawn according to metabolic needs.

Patterns of locomotion are closely tied to skeletal components. Throughout the evolution of land-inhabiting vertebrates from ancestral fish, the skeletal and muscular systems and the mode of locomotion of the animal offer excellent examples of complementarity of structure and function, as well as examples of adaptation to specific environments. At this point the teacher may wish to introduce the concept of adaptation by means of natural selection, as exemplified by the varied patterns of the vertebrate skeleton, but this should be only a brief mention, as a prelude to a more detailed discussion that will come in Chapters 34 and 35.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 461)

1. Bilateral means "two sides." In a bilaterally symmetrical animal, a line drawn down the center of the animal, from head to tail, divides it in two approximately equal halves. In a radially symmetrical organism, the body is arranged like a wheel around a central point with no definite head end, and no right or left. The fact that bilaterally symmetrical animals have evolved more effective locomotion (and those with exoskeletons and endoskeletons more effective support for their bodies) has made them more successful than radially symmetrical forms in adapting to a terrestrial life.
2. With a skeleton for the attachment of muscle, locomotion becomes more effective and rapid than in organisms without skeletons, such as the earthworm.
3. Striated muscle cells (or fibers) consist of a number of individual muscle fibrils containing dozens of lengthwise filaments of actin and myosin. The chemical energy of ATP causes the actin and myosin filaments to slide past each other and the distance between the Z bands shortens, thus contracting each fibril in a muscle cell.
4. Contraction of muscle fibers involves the respiratory, circulatory, digestive, and excretory systems, as well as the muscular system. Glucose brought to the muscle fiber during rest is converted into glycogen and stored in the muscle. Following contraction of the muscle, this glycogen is converted into glucose and oxidized to lactic acid.

These oxidative steps yield enough ATP to replenish the supply of creatine phosphate and ATP used by the contraction. The remaining lactic acid is then used to help replenish the glycogen supply; one-fifth of the lactic acid is oxidized, providing the energy necessary to convert the remaining four-fifths back to glycogen. Thus, the contraction and recovery mechanisms of muscle fibers demonstrate a self-regulating and homeostatic capacity involving glycogen, glucose, ATP, creatine phosphate, lactic acid, and muscle proteins (such as myosin and actin).

5. Exoskeletons are rigid and heavy. They restrict an animal's movement and limit growth, making it necessary for the animal to molt in order to increase in size. If exoskeletons contained living cells and were able to grow, their limitations would presumably be fewer.
6. Opposing muscles are those that work in pairs. When one muscle of a pair contracts, it moves the skeleton in a characteristic way. For the skeleton to move back to its original position, the other muscle of the pair must contract as the first relaxes. The opposing muscles thus oppose one another in the directional movement they produce. Without them, the skeleton could not "recover" from a previously produced movement, or move in the opposite way.

REFERENCES

"Invitations to Enquiry" Nos. 32, 24, and 35 in the *Teachers' Handbook* use muscle and skeleton as subjects to elucidate function.

Useful books:

Allen, G. 1939. *Bats*. Dover, New York

Bourne, G. (ed.), 1960. *The Structure and Function of Muscle*, three volumes. Academic Press, New York

Griffin, D. 1962. *Animal Structure and Function*. Holt, Rinehart and Winston, New York

Hardin, G. 1961. *Biology: Its Principles and Implications*. W. H. Freeman, San Francisco

Milne, L., and M. Milne. 1958. *The Biotic World and Man*, 2nd ed. Prentice-Hall, Englewood Cliffs (N. J.)

Sleigh, M. A. 1963. *The Biology of Cilia and Flagella*. Pergamon, New York

Szent-Györgyi, A. 1951. *The Chemistry of Muscular Contraction*, 2nd ed. Academic Press, New York

Articles in journals:

Hayashi, T. 1961. "How Cells Move." *Sci. Am.* 205 [3] 184

Huxley, H. E. 1958. "The Contraction of Muscle." *Sci. Am.* 199 [5] 66

FILMS

The Multicellular Animal, Part IV: *Muscles*, No. 8, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Human Skeleton, 1954, (sd, b&w, 12 min), p or r, UW

The Muscular System, 1951, (sd, b&w, 11 min), p or r, UW

Skeleton, 1953, (sd, b&w, 12 min), p or r, EBF

The Spinal Column, 1956, (sd, b&w, 11 min), p or r, EBF

Life, Time and Change, Part X: *From Water to Land*, No. 10, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 27 REPRODUCTION IN ANIMALS

RATIONALE

Reproduction has been considered several times previously in the course—in the mitotic division of cells, and in viruses, bacteria, and various types of plants. In this chapter, the student learns of reproduction in animals (which should be compared with, and contrasted to, reproduction in the organisms studied earlier).

The advantages of sexual reproduction over asexual reproduction, in introducing a variety of genetic types upon which natural selection can act, have been emphasized previously. Partly because sexual reproduction has obvious evolutionary advantages, and partly because it is the more common and more complex of the two types of animal reproduction, it is the pattern emphasized in this chapter. The male sex cell is the sperm, the female sex cell the ovum. The union of the two creates the cell from which a new individual develops.

External fertilization is one method many aquatic animals utilize. However, this is a somewhat haphazard process, successful only because of the enormous number of eggs and sperms produced. A better method of ensuring the union of sperms and eggs is internal fertilization. The sequence of reproductive specializations involves a means of accomplishing fertilization internally, a reduction in the number of eggs produced, storage of a food supply in the egg, and the protective retention of the developing embryo in the reproductive tract of the female. The development of an amnion (which protects the embryo in a liquid-filled cavity), a placenta (which brings in a constant food supply), and mammary glands (which supply newborn young with a source of energy and the materials needed for growth and development) are major evolutionary steps that help ensure the viability of offspring.

Only terrestrial animals have developed embryonic membranes in which the embryo is protected both from mechanical injury and from the danger of desiccation.

Mammalian reproduction is studied in terms of the platypus, the opossum, the cow, and man. For the latter, the male and female reproductive organs are introduced, the cyclical nature of the female reproductive system is emphasized, and human birth, with its necessary physiological changes, is discussed briefly.

The coordination of the female reproductive cycle, involving the pituitary glands, ovaries, and the uterus, is another example of the role of the endocrine system in maintaining internal regulation. This example is dealt with in some detail by the text.

With the proper basis laid earlier in the course, experiences show that this chapter on animal reproduction, and especially the sections on human reproduction, can be taught factually and without embarrassment to either teacher or class, in part because of the basic interest of the student, and in part because of the lucid and unemotional emphasis of the chapter upon reproduction as the most essential process involved in the maintenance of species.

Since 1960, feedback from teachers who have taught this material has indicated complimentary reactions from students and parents for a straightforward and complete discussion of a most important biological function.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS *(text page 481)*

1. Insofar as binary fission, spore formation, and budding do not involve the fusion of the nuclei of two cells, and also do not involve the process of meiosis, they are somewhat similar methods of asexual reproduction.
2. Individuals produced by asexual reproduction normally have the exact genetic pattern of the parent; thus they should be identical with the parent in all hereditary traits.
3. The two basic events in sexual reproduction are meiosis and fertilization.
4. Meiosis reduces the chromosome number in the sex cells to a monoploid condition. Fertilization combines two monoploid cells, one from each parent, to form a diploid cell bearing genetic material from both the male and female parent.
5. In sexual reproduction each parent produces a variety of gametes, which differ in the genes they contain. Thus, when ova and sperms combine at fertilization, many different variations in offspring are produced.
6. The sperm and the egg each contribute half the genetic complement of the offspring. Thus, quantitatively they are similar. Qualitatively, however, they differ, since their respective genetic contributions do not consist of identical genes and chromosomes.
7. Internal fertilization ensures a greater opportunity for the sperm to fertilize the egg than is possible in external fertilization.
8. The embryo that has an adequate supply of food and is protected from predation has a better chance of developing to maturity, and thus being able to reproduce and help maintain the species, than one provided with little food or with no protective membranes or maternal protection. The more effective the food source and the greater the amount of protection, the better the chance for species survival.
9. Before the evolution of embryonic membranes, animal eggs could develop only in water. The amnion makes the aquatic environment unnecessary (or rather, makes an aquatic environment possible on land), while the allantois provides for respiration and waste disposal, and the yolk sac provides the necessary food. Without these features, eggs could not survive on land.
10. Embryos that develop inside the female are protected in a constant internal environment, are provided with food and oxygen, and have their metabolic wastes disposed of by the better developed systems of the maternal parent. Such protection and nourishment gives the embryo a better chance to develop, and the species a better chance to survive.
11. Placental mammals may have attained internal development of offspring through the retention of the egg in the uterus and the evolution of the placenta. The placenta made possible the prolonged nourishment of the embryo by the female parent; the amount of yolk was no longer a limiting factor.
12. Estrogen affects the uterus by increasing its mitotic activity, blood supply, and amount of tissue fluid. Progesterone then stimulates the thickening of the uterus and effects gland and blood vessel development, so that a rich, spongy layer is produced, suitable for the attachment of a fertilized ovum.

13. The chorion of the human, together with the adjacent part of the uterine tissue, makes up the placenta. The amnion grows around the embryo itself and becomes filled with fluid that keeps the embryo moist and protects it from adhesions and mechanical injury. The yolk sac in humans is a degenerate structure and does not contain yolk. The allantois, together with the chorion, helps form the placenta, and the stalks of the allantois and yolk sac are surrounded by amniotic folds that form a tube—the umbilical cord—connecting the developing embryo with the placenta (and containing the remnants of the yolk sac and allantois).
14. The role of the ovary in the control of the reproductive cycle involves the release from the ovarian follicle of estrogens, which stimulate uterine growth. After ovulation, progesterone is secreted from the corpus luteum and further acts on the uterus. If pregnancy does not occur, the decrease of progesterone influences the onset of menstruation and starts the cycle over.
15. The pituitary gland influences both the ovary and the uterus. The pituitary hormone FSH stimulates the ovarian follicles to grow. After growth of the follicles, the pituitary hormone LH induces ovulation, and the follicles change to corpora lutea. A third pituitary hormone, LTH, stimulates the development and secretion of the mammary glands, in addition to stimulating the corpora lutea to secrete progesterone. Both FSH and LH are necessary in order for developing follicles to secrete estrogen. Different activities of the ovaries occur in the presence of different concentrations of the pituitary hormones. Thus, the pituitary hormones of mammals play a major part in influencing the activities of both the ovary and uterus during the female reproductive cycle.

REFERENCES

Invitation to Enquiry No. 25 (page 130) in the *Teachers' Handbook* uses as its subject the pituitary-gonad mechanism.

Useful books:

Best, C. H., and N. B. Taylor. 1963. *The Human Body: Its Anatomy and Physiology*, 6th ed. Holt, Rinehart and Winston, New York
Kon, S. K., and A. T. Cowie (eds.), 1961. *Milk: The Mammary Gland and Its Secretion*, Vol. I. Academic Press, New York
Langdon-Davies, J. *Seeds of Life*. New American Library, New York
Lloyd, C. W. (ed.), 1959. *Recent Progress in the Endocrinology of Reproduction*. Academic Press, New York
Zuckerman, S. (ed.), 1962. *The Ovary*, two volumes. Academic Press, New York

FILMS

Meiosis, 1963, (sd, b&w or c, 16 min), p or r, EBF
Mitosis, 1961, (sd, b&w or c, 24 min), p or r, EBF
Reproduction, Growth and Development, Part V: *Patterns of Reproduction*, No. 1, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Reproduction, Growth and Development, Part V: *The Sex Cells*, No. 3, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Reproduction, Growth and Development, Part V: *Fertilization*, No. 4, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Human Reproduction, 1948, (sd, b&w, 23 min), p or r, McGraw-Hill
Reproduction, Growth and Development, Part V: *An Animal Life Cycle*, No. 2, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Reproduction, Growth and Development, Part V: *Reproductive Hormones*, No. 8, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 28 THE DEVELOPMENT OF ANIMALS

RATIONALE

The process that begins with fertilization and ends with the formation of the adult body is called development, and the study of development is called embryology. To leave students with no deeper knowledge of development than that portion of the reproductive story involved with fertilization (covered in Chapter 27) would be to give them an incomplete understanding of the process whereby the union of two gametes produces a new individual.

The four main features of development are: (1) an increase in the number of cells by mitosis; (2) growth; (3) cellular differentiation; and (4) organization of the differentiated cells into tissues, organs, and systems.

Amphibian embryos are used as an example of typical vertebrate embryos that demonstrate the four processes mentioned above. (Here again, students encounter reasons for the use of animals other than man in experimentation. A great amount of information of value to the study of man or any other animal can be obtained by studying apparently unrelated, or less significant, animals. This is another expression of the theme of unity that was established by the first eight chapters of the textbook—a theme that has been further illuminated by studies of different types of organisms, all of which have essential properties in common.) Because amphibian embryos are easy to get, easy to maintain, and easy to use in experiments, they are ideal for development studies. The patterns of development exemplified by the study of a salamander are explained by both text and illustrations, in such a way that students should become familiar with the major patterns of development without getting involved in minute details.

The common feature of vertebrate development is the formation of the three embryonic layers from which all of the tissues and organs of the adult organism will arise by the processes of differentiation and organization.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 493)

1. In the early development of the fertilized egg, the vegetal hemisphere becomes oriented downward, the animal hemisphere upward, and cleavage of the egg is initiated.
2. The four processes involved in embryonic development are: (a) an increase in the number of cells; (b) growth; (c) cellular differentiation;

and (d) organization of differentiated cells into tissues, organs, and systems.

3. Salamander or other amphibian embryos are extremely hardy, and they do not require extra food because of their contained yolk. The eggs are easy to collect in almost all areas of the world, and they can be artificially fertilized as necessary. Furthermore, the embryonic covering of amphibian embryos is usually transparent, so that developmental details are not obscured.
4. By the time the fertilized egg of the marbled salamander has developed for 29 hours, the process of cell division has produced hundreds of cells, which are particularly small at the animal hemisphere. The embryo consists, at this time, of a hollow ball of cells filled with fluid and is termed a blastula. The cells, while superficially alike, are chemically more different than their appearance would suggest.
5. By the time the embryo is 50 hours old, a rearrangement of cells is taking place, caused by the movement of surface cells into the interior through the blastopore; in other words, the process of gastrulation is proceeding. By the 80th hour, the cells on the surface of the embryo are largely those that will form ectodermal structures, the remaining cells having moved to the interior through the dorsal lip of the blastopore. The blastoporal groove at this stage now forms a complete circle. By the 105th hour, the neural ridges have enlarged, moved together, and fused at their top edges to form a tube, which will be the dorsal hollow nerve tube. The part already closed by this time will form the spinal cord, while the anterior, still opened area will be the brain.
6. The fact that the basic features of all vertebrates are alike suggests common developmental patterns in the early stages, and, in later development, variations that enable us to distinguish one species from another. These common features provide strong evidence of descent from a common ancestor.
7. From the ectoderm are derived the nervous system and the skin and its covering (hair, scales, feathers, etc.). From the mesoderm are derived muscle, skeleton, circulatory system, excretory system, reproductive system, and inner layer of skin. From the endoderm comes the lining of the digestive and respiratory systems.

REFERENCES

Invitation to Enquiry No. 37 (page 184) of the *Teachers' Handbook* deals with the subject of embryonic circulation.

Useful books:

Berrill, N. J. 1961. *Growth, Development, and Pattern.* W. H. Freeman, San Francisco

Patten, B. 1953. *Early Embryology of the Chick,* 4th ed. McGraw-Hill, New York

——— 1953. *Embryology of the Pig,* 3rd ed. McGraw-Hill, New York

——— 1953. *Human Embryology,* 2nd ed. McGraw-Hill, New York

Rugh, R. 1953. *The Frog—Its Reproduction and Development.* McGraw-Hill, New York

Sussman, M. 1960. *Animal Growth and Development.* Prentice-Hall, Englewood Cliffs (N. J.)

Torrey, T. 1962. *Morphogenesis of the Vertebrates*. John Wiley & Sons, New York

Waddington, C. H. 1962. *New Patterns in Genetics and Development*, Columbia University Press, New York

FILMS

Reproduction, Growth and Development, Part V: *Theories of Development*, No. 5, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Reproduction, Growth and Development, Part V: *Development of Organs*, No. 7, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

The Fish Embryo: From Fertilization to Hatching, 1963, (sd, c, 12 min), p or r, EBF

The Chick Embryo: From Primitive Streak to Hatching, 1961, (sd, b&w or c, 13 min), p or r, EBF

The Reproductive Processes of the Frog, Rana pipiens, 1948, (si, b&w, 45 min), p, Roberts Rugh

Reproduction Among Mammals, 1937, (sd, b&w, 11 min), p or r, EBF

Sea Urchin, 1950, (sd, b&w, 8 min), p or r, UW

Biography of the Unborn, 1956, (sd, b&w, 16 min), p or r, EBF

Development of the Chick Embryo, 1953, (sd, b&w or c, 6 min), p or r, Coronet

Life Before Birth, 1960, (sd, b&w, 26 min), p, Carousel

Life Cycle of Trout, 1950, (sd, b&w, 10 min), p or r, UW

Chapter 29 THE ANALYSIS OF DEVELOPMENT

RATIONALE

Two theories of development, preformation and epigenesis, are presented to the students with supporting evidence, and they are to determine the accepted theory by consideration of the evidence. As they deal with development through the experimental work of Roux and Driesch, in contrast to the nonexperimental approach of Aristotle, the students will discover that development is largely epigenetic.

Epigenesis is more difficult to explain than preformation. The work of Spemann on the development of the neural tube has provided much evidence upon the cause of differentiation. The phenomenon of embryonic induction, as discovered by Spemann, accounts for many of the observed features of differentiation.

Two examples of continued development in adult animals are regeneration and abnormal differentiation, both of which provide interesting examples of continued growth and differentiation of tissues.

This chapter serves as a culmination of the three-chapter sequence that began with reproduction. From these chapters, students should have gained an understanding that will permit them to retain a knowledge of the basic principles of the formation of a new individual.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text pages 503-04)

1. On the basis of what was known of mitosis, each cell in a dividing zygote would be expected to be exactly like the others. Accepting epigenesis thus posed the difficulty of cell differences that could not be explained until the concepts of differentiation and organization were introduced.
2. In the classical sense, yes. There is no little man in the sperm. However, the embryo does receive a preformed genetic makeup. It is the genes that preserve the genetic continuity of the offspring.
3. The experiments of Roux were first interpreted as evidence of preformation, and those of Driesch as evidence of epigenesis. Today, the experiments of both men, considered together, are interpreted as evidence that development is largely epigenetic.
4. Spemann hypothesized that the ectoderm must be influenced by other parts of the embryo in order to develop into a neural tube. Specifically, he thought that the mesoderm stimulated the ectoderm to develop into the nervous system. When he removed the mesoderm from beneath the ectoderm, the ectoderm did not develop into nervous tissue, nor did ectoderm that was removed from the embryo develop into nervous tissue. These findings supported his hypothesis.
5. The work of Niu, wherein a piece of mesoderm from the dorsal lip area was left in a salt solution for a few hours, then was removed and replaced by a piece of ectoderm, showed that ectoderm when in a solution previously exposed to mesoderm would form nervous tissue. Since the ectoderm differentiated just as it would have done in the presence of the mesoderm, obviously the mesoderm must have left some kind of chemical messenger behind in the solution. Later the chemical messenger was shown to be a nucleic acid.
6. Regeneration resembles embryonic development in that it involves the same kinds of processes that were necessary for the initial development of the organism.
7. The phenomenon of regeneration is widely distributed throughout the animal kingdom, from sponges and coelenterates to man, although not to the same degree in each. Apparently, regeneration is limited to relatively unspecialized cells. Highly specialized cells, such as almost all of the cells found in the higher vertebrates, do not lend themselves to being regenerated easily.
8. Cancer is a problem of abnormal cell division and metabolism. The rapidly developing cancer cells get the raw materials they use for division and growth from the normal cells or organs. Thus, as cell division is one of the four major components of development, cancer can be considered to be a developmental problem; a better understanding of developmental processes may therefore provide clues as to how to stop abnormal cell growths.

REFERENCES

Useful books:

Ebert, J. 1963. *Development.* Holt, Rinehart and Winston, New York

Moore, J. 1963. *Heredity and Development.* Oxford University Press, New York

Rudnick, D. 1962. *Regeneration.* Ronald Press, New York

Willier, B., and J. Oppenheimer. 1964. *Foundations of Experimental Embryology*. Prentice-Hall, Englewood Cliffs (N. J.)

Articles in journals:
Fischberg, M., and A. Blackler. 1961. "How Cells Specialize." *Sci. Am.* 205 [3] 124
Frieden, E. 1963. "The Chemistry of Amphibian Metamorphosis." *Sci. Am.* 209 [5] 110
Singer, M. 1958. "The Regeneration of Body Parts." *Sci. Am.* 199 [4] 79
Waddington, C. 1953. "How Do Cells Differentiate?" *Sci. Am.* 189 [3] 108
Wigglesworth, G. 1959. "Metamorphosis, Polymorphism, Differentiation." *Sci. Am.* 200 [2] 100

FILMS

Reproduction, Growth and Development, Part V: *Theories of Development*, No. 5, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Reproduction, Growth and Development, Part V: *Regeneration*, No. 9, 1961, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Cancer, 1953, (sd, b&w or c, 12 min), p or r, EBF
Dividing Cancer Cells Cultivated Outside the Body, (si, b&w, 8 min), Carnegie
Development of the Nervous System, (si, b&w, 19 min), Northwestern University

S.C.E.R.T., West Bengal
Library
Calcutta
25/3, B. C.

PART III
CONTINUITY

Chapter 30 PATTERNS OF HEREDITY

RATIONALE

Unity within diversity has been the combined theme of Parts I (Chapters 1-8) and II (Chapters 9-29) of the textbook. But how did both the unity and the diversity come to be? The origin of the first organic matter from an inorganic environment is lost in antiquity (nonetheless, in later chapters we shall attempt to reconstruct it). There is ample direct evidence, however, that in the course of time organisms have changed, on the whole becoming more diverse and implying thereby a common ancestry somewhere in the past. Unity, in other words, must have preceded diversity and today remains strongly evident within it.

Through all of life from the beginning runs a continuity, maintained by reproduction and protected by diversity and variation. It is this continuity of life that constitutes Part III of the textbook.

The first chapter in Part III, based upon previous studies of sexual reproduction, introduces the study of genetics—the branch of biology that is concerned with heredity and variation in successive generations of organisms. The chemical instructions received from parents by way of the reproductive cells constitute the heredity of a new individual. But while heredity determines what the new individual may become, both heredity and environment determine what it does become. The examples cited by the textbook include both plants and animals, and serve to emphasize the complex heredity-environment interaction.

The phenomenon of heredity has been used by man for thousands of years in selectively breeding animals, such as dogs for hunting, cows for milk, and sheep for wool. It was not until one hundred years ago, however, when Gregor Mendel made his pioneer study of heredity in peas, that the basis for selective breeding began to be understood.

The genetic story is introduced through the work of Mendel. Students are led through Mendel's original hypothesis and his experiments to his conclusions, which can be summarized as follows: (1) determiners of inheritance exist; (2) for any particular hereditary trait, there are two determiners, which may or may not be alike; (3) if the determiners (alleles) are different, one will be dominant and the other recessive; (4) the alleles separate during gamete formation, and each gamete receives only one of the allele

pair; and (5) there is a random uniting of gametes at fertilization, resulting in a predictable ratio of alternative traits in offspring.

Mendel's work is meaningless without a discussion of probability, which introduces the dimension of quantitative interpretation of data into the study of biology. While some students may tend to react unfavorably to the introduction of mathematics, the mathematics involved is essentially simple algebra, to which students at this level have already been exposed. The algebraic multiplication can be easily taught and quickly learned if the initial block of some students toward mathematical manipulations is rapidly overcome.

The work of Mendel involved single trait inheritance only in plants; nonetheless, his conclusions, within the framework of their obvious limitations, find general application among all living organisms. A number of problems involving calculations of probabilities in heredity are suggested for student exercises. These should be worked out either in class or as homework to ensure that the students comprehend the principles involved in single-factor inheritance.

The study of single-factor inheritance leads to the study of multiple alleles, whereby more than two different alleles of the gene affect a specific trait. Human blood type, for example, is determined by multiple alleles, and the problems suggested in the text serve to dramatize the effect of such alleles.

Simultaneous consideration of two different traits introduces a glimpse of the progression of probabilities in variation among offspring. From an understanding of the 3 : 1 phenotypic ratio in Mendel's experiments to the 9 : 3 : 3 : 1 phenotypic ratio in a dihybrid cross, students are given the essential data for reaching their own limit of conclusions about Mendel's laws (especially independent assortment) and all the complex possibilities of variation.

Another complication lies in store for the students, when they discover that not all traits with which we are familiar seem to express themselves either as single factors or multiple alleles. These continuously varying traits involve several different pairs of genes. Comprehension of this idea has led to many genetic improvements of crop plants and animals, including the development of hybrid corn and the phenomenon of the "double cross," which masks the effect of undesirable genes. Hybrid corn alone contributed over 2 billion dollars to the American economy during the years 1942-45.

The possibilities that are opened for mankind by the intelligent use of simple genetic principles should impress students with the value of the work of geneticists. The promise for the future, in spite of man's carelessness with his resources of today, is very great, provided only that carelessness does not continue (a topic that will be discussed more fully in Chapter 40).

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text pages 525-26)

1. Each ovum and sperm contains a randomly selected monoploid set of chromosomes, which combine at fertilization. Thus, each ovum and sperm contributes half the genetic complement of a new organism.
2. The contribution of the ovum to the new individual differs from that of the sperm because of the greater cytoplasmic contribution made by the ovum.
3. In the fruit fly, environmental temperature affects the curling of the wings to the extent that it can cause the wings to be straight regardless of the presence of the hereditary makeup for curly wings. In green

plants, despite the genetic instructions to produce chlorophyll, none will be produced unless the plants get light. In human beings, environment apparently influences the development of intelligence; identical twins who have similar or identical hereditary complements but are raised in different environments differ somewhat in intelligence (at least as measured by I.Q. tests). The environment thus controls the expression of certain genes.

4. The features of the planning of Gregor Mendel's experiments that were important in his success were: (a) he studied a large number of offspring; (b) he limited each cross to a single pair of alternative traits; and (c) he used mathematics to analyze his data and arrive at the theory explaining his results.
5. Mendel chose to work with garden peas because they are easy to cultivate and cross, the generation time is reasonably short, numerous varieties are available, and the offspring of crosses between the varieties are fertile. Of greatest importance to him was the structure of the pea flower, which allows it to be self-pollinated and not cross-pollinated by bees or other insects.
6. To ensure that the parent pea plants were pure-bred for the traits he was observing, Mendel let the plants fertilize themselves for a number of generations. He studied the offspring of each generation to make sure they were like one another and like the parent plant.
7. In order to eliminate the variable effects of environment on the inheritance of his garden peas, Mendel must have grown them in similar soils, watered them and fertilized them in a similar manner, and, insofar as possible, made sure that they were exposed to similar weather conditions of rain, wind, and sunlight.
8. If homozygous dominant plants provided eggs and homozygous recessive plants were pollen sources, all of the offspring would be heterozygotes. If the situation were reversed, the same results would be still obtained. The significance of these results is that each parent, whether through egg or sperm, contributes equally to the hereditary complement of the offspring.
9. The use of large numbers of individuals in genetics experiments gives more reasonably valid results because the large numbers minimize errors due to sampling and thus, in terms of probability, provide more accurate data for mathematical analysis.
10. The following are heterozygotes: I^AI^B, Bb, I^Bi, Aa. The homozygotes are: AA, ss, BB, rr, ii. The following genotypes would have the same phenotypes: AA and Aa, Bb and BB. The following have only two given alleles: AA, ss, Bb, Aa, BB, rr. The genotype series showing multiple alleles is: I^AI^B, I^Bi, ii.
11. A test cross is one in which the organism to be tested is mated with one that is known to have the homozygous recessive genotype for the trait in question. Because each offspring from such a mating must receive one recessive gene from the homozygous recessive parent, the phenotype of the offspring will depend on the genotype of the parent being tested. If even one offspring demonstrates the homozygous recessive trait, the tested parent must be heterozygous.
12. Two dominant alleles or a dominant and recessive allele produce a dominant characteristic. Two recessive alleles produce a recessive characteristic. A dominant and a recessive allele may produce an incompletely dominant characteristic, such as pink color in four-o'clocks.

13. While it is true that only two genes for a given trait (in single-trait inheritance) may occur together in the cells of any given individual, many more than two different alleles of the gene may exist in the members of a large population. Three alleles, for example, determine human blood types. Though they may be paired in any combination, only two can be present in a single individual. The genes for blood types A and B determine those blood types both in a homozygote and in a heterozygote in combination with the recessive for 0. When they occur together, the blood type is AB. Only in the absence of both these genes is the blood type 0.

14. There are 64 possible genetic combinations from a trihybrid cross. Any homozygous combination will occur in 1/64th of the cases (example, AABBCC). Any single heterozygote combination will occur in 1/32nd of the cases (example, AaBBCC). Any double heterozygote combination will occur in 1/16 of the cases (example, AABbCc). Any triple heterozygote combination will occur in 1/8th of the cases (example, AaBbCc).

The algebraic solution is derived by performing the A cross, B cross, and C cross separately and then combining the results of the three crosses by algebraic multiplication.

The first three hybrid crosses are:

Aa × Aa yields 1/4 AA + 1/2 Aa + 1/4 aa
Bb × Bb yields 1/4 BB + 1/2 Bb + 1/4 bb
Cc × Cc yields 1/4 CC + 1/2 Cc + 1/4 cc

The first two crosses above can be combined as:

1/4 AA + 1/2 Aa + 1/4 aa
× 1/4 BB + 1/2 Bb + 1/4 bb

The results of this cross are:

Genotype	Phenotype
1/16 AABB	tall black
1/8 AaBB	tall black
1/16 aaBB	short black
1/8 AABb	tall black
1/4 AaBb	tall black
1/8 aaBb	short black
1/16 AAbb	tall white
1/8 Aabb	tall white
1/16 aabb	short white

The combination of these nine genotypes with the third hybrid cross (1/4 CC + 1/2 Cc + 1/4 cc) is:

1/16 AABB + 1/8 AaBB + 1/16 aaBB + 1/8 AABb + 1/4 AaBb + 1/8 aaBb + 1/16 AAbb + 1/8 Aabb + 1/16 aabb
× 1/4 CC + 1/2 Cc + 1/4 cc

The results, in tabular form, are:

Genotype	Phenotype
1/64 AABBCC	tall black curly
1/32 AaBBCC	tall black curly

1/64	aaBBCC	short black curly
1/32	AABbCC	tall black curly
1/16	AaBbCC	tall black curly
1/32	aaBbCC	short black curly
1/64	AAbbCC	tall white curly
1/32	AabbCC	tall white curly
1/64	aabbCC	short white curly
1/32	AABBCc	tall black curly
1/16	AaBBCc	tall black curly
1/32	aaBBCc	short black curly
1/16	AABbCc	tall black curly
1/8	AaBbCc	tall black curly
1/16	aaBbCc	short black curly
1/32	AAbbCc	tall white curly
1/16	AabbCc	tall white curly
1/32	aabbCc	short white curly
1/64	AABBcc	tall black straight
1/32	AaBBcc	tall black straight
1/64	aaBBcc	short black straight
1/32	AABbcc	tall black straight
1/16	AaBbcc	tall black straight
1/32	aaBbcc	short black straight
1/64	AAbbcc	tall white straight
1/32	Aabbcc	tall white straight
1/64	aabbcc	short white straight

Some students may solve this problem by means of a "checkerboard." If so, they will fill in 64 squares, using the following eight gametes for each parent: ABC, AbC, ABc, Abc, aBC, abC, aBc, abc.

REFERENCES

Useful books:

Bonner, D. 1961. *Heredity*. Prentice-Hall, Englewood Cliffs (N.J.)

Carson, H. 1963. *Heredity and Human Life*. Columbia University Press, New York

Crow, J. 1963. *Genetics Notes*. Burgess, Minneapolis (Minn.)

Gardner, E. J. 1960. *Principles of Genetics*. John Wiley & Sons, New York

King, R. C. 1962. *Genetics*. Oxford University Press, New York

Levine, R. P. 1962. *Genetics*. Holt, Rinehart and Winston, New York

Moore, J. 1963. *Heredity and Development*. Oxford University Press, New York

Penrose, L. 1963. *Outline of Human Genetics*, 2nd ed. John Wiley & Sons, New York

Peters, J. (ed.), 1959. *Classic Papers in Genetics*. Prentice-Hall, Englewood Cliffs (N.J.)

FILMS

Genetics, Part VI: *Science of Genetics*, No. 1, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *Mendel's "Segregation,"* No. 2, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *Mendel's "Recombination,"* No. 3, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *Blood Groups, Skin Color and Gene Pools*, No. 7, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *Nature and Nurture*, No. 9, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Heredity and Environment, 1959, (sd, b & w, 30 min), p or r, Indiana

Heredity: Many Pairs of Genes, 1960, (sd, b & w, 30 min), p or r, Indiana

Heredity: Mendel's Experiments, 1960, (sd, b &w, 30 min), p or r, Indiana

Genetic Investigations, 1961, (sd, b & w or c, 12 min), p or r, Indiana

Genetics, No. 1: *Heredity and Variation*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Genetics, No. 2: *Mendel's Proof of the Existence of Genes*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Chapter 31 THE CHROMOSOME THEORY OF HEREDITY

RATIONALE

This chapter concerns itself with the theoretical basis of the work of Gregor Mendel, and how it was built upon by other men. Mendel's experimental data were confirmed for single-trait inheritance in many different kinds of organisms. Increasingly, the regularity of the data suggested a definite physical basis—in other words, that Mendel's "determiners of inheritance" must be actual structures in the cell. In earlier chapters, meiosis was introduced; it is now presented in detail in order that students may follow Walter Sutton's progress in relating the behavior of Mendel's genetic determiners to the behavior of the chromosomes during meiosis. Sutton can be seen to have had good reason to suggest chromosomes as the logical site for genes within the cell. This chapter thus ties together the principles of genetics and the features of sexual reproduction in order to derive the chromosome theory of heredity.

When originally proposed, the chromosome theory of heredity took into account all available data, and with few modifications it has continued to account for all new data as they have appeared over the years. Thus, for example, the discovery of the sex chromosomes and their role in sex determination further focused attention on the role of the chromosomes in heredity. In studies of sex-linked inheritance, Thomas Hunt Morgan found direct relationships between particular hereditary traits and particular chromosomes—a dramatic confirmation of Sutton's theory. Using the chromosome theory as developed by Sutton, Morgan explained exceptions to Mendel's principle of independent assortment by assuming that genes located on the same pair of chromosomes behaved as if they were linked together. Studies of linkage then provided further confirmation of Sutton's theory and enabled researchers to map the locations of genes on a chromosome. Ultimately, Bridges' work on nondisjunction provided the final, convincing demonstration that the genes are indeed located on chromosomes;

the chromosome theory of heredity was established. The extension of Bridges' work on nondisjunction to humans shows that this phenomenon, which can be further exaggerated by radiation, may result in gross human aberrations.

Through the historical approach students are led, as preceding paragraphs have described, from the work of Mendel and his postulation of hereditary determiners to the work of twentieth century investigators who have confirmed the existence of such determiners (genes) and their location on the chromosomes. As an example of the experimental approach and scientific inquiry, the chromosome theory provides an outstanding opportunity to appreciate the methods of science.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 547)

1. Because Mendel's observations were only on the phenotypic expression of his postulated determiners—in other words, the result, not the cause he could not provide direct evidence for the existence of genes or their location.
2. Mendel's concept of independent assortment was that the two determiners for a given characteristic separate (during meiosis) independently of the separation of determiners for any other trait. In other words, the association of dominant and recessive determiners for different traits occurred at random (according to chance). At fertilization, male and female gametes also united at random, pairing the genes for different traits in whatever combinations resulted from the chance occurrence of the genes in the gametes.
3. In mitosis each cell receives a chromosome complement identical to that of the parent cell. In terms of hereditary determiners, therefore, mitosis provides a physical basis whereby each part of a plant (or animal) receives the same genetic instructions that were present in the fertilized egg. In meiosis and gamete formation, the separation and chance assortment of the chromosomes into monoploid gametes, and the exchange and recombination of parts of chromatids in synapsis, parallel Mendel's conclusions about the behavior of the hereditary determiners, which by analysis of his data were indicated as elements that segregated and assorted independently of one another.
4. To account for Mendel's observations, one would have had to assume that each gamete contained a single member of each pair of determiners, and that these determiners paired or combined with each other randomly at fertilization. Therefore, it would have been necessary to postulate a mechanism whereby the determiners would first be separated, in the preparation of gametes (meiosis), and then be recombined at random during fertilization.
5. Following a cross of a white-eyed male and red-eyed female, Morgan observed that, while Mendelian ratios were preserved, all the white-eyed flies of the F_2 generation were males. There is a difference between the chromosomes of male and female *Drosophila;* the Y chromosome in the male seems to be "inert." Consequently, a recessive gene on the X chromosome always affects the phenotype and is thus recognizable in the male fly, since there is no corresponding dominant allele on the Y chromosome to mask the effect of the recessive gene. Thus, Morgan found evidence of a direct relation between a particular hereditary trait and a particular chromosome.

6. If A and B are 20 crossover units apart, and A and C are eight crossover units apart, then the expected crossover between B and C would be 12 percent if C is between A and B, or 28 percent if A is between C and B.
7. The work of Bridges with nondisjunction provided evidence that the distribution of specific genes is identical with the distribution of specific chromosomes. In his work with eye color in *Drosophila*, Bridges established beyond question that genes are physically associated with chromosomes. Microscopic examinations of the chromosomes of the experimental offspring showed that the actual pattern of the X and Y chromosomes corresponded to the predicted pattern for the phenotypes under consideration. Bridges found perfect agreement among the inheritance of vermilion eye color, the sex of the fly, and the chromosome distribution according to the nondisjunction hypothesis.
8. In *Drosophila*, the number of X chromosomes (in relation to the number of autosomes) determine the sex of the fly. In humans, the presence of a single Y chromosome always produces a male, no matter how many X chromosomes may be present.

REFERENCES

Useful books:

Brachet, J., and A. Mirsky (eds.), 1961. *The Cell.* Vol. III, *Meiosis and Mitosis.* Academic Press, New York

Burla, H., and Honegger-Lavater. *Genetics.* Dell, New York

Levine, L. (ed.), 1963. *Symposium on the Cell in Mitosis.* Academic Press, New York

Moore, J. A. 1963. *Heredity and Development.* Oxford University Press, New York

Peters, J. 1959. *Classic Papers in Genetics.* Prentice-Hall, Englewood Cliffs (N.J.)

Sager, R., and F. Ryan. 1961. *Cell Heredity.* John Wiley & Sons, New York

Sinnott, E. W., L. C. Dunn, and T. Dobzhansky. 1958. *Principles of Genetics.* McGraw-Hill, New York

FILMS

Genetics, Part VI: *Genes and Chromosomes*, No. 5, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *Chromosomes and Sex*, No. 6, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Meiosis, 1963 (sd, b & w or c, 16 min), p or r, EBF

Mitosis, 1961 (sd, b & w or c, 24 min), p or r, EBF

Heredity: The Sex Chromosomes, 1960, (sd, b & w, 30 min), p or r, Indiana

Genetics, No. 3: *Mitosis*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Genetics, No. 4: *Meiosis*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Genetics, No. 12: *Sex-Linked Inheritance*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Genetics, No. 13: *Sex Determination I*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Genetics, No. 15: *Linkage*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Chapter 32 GENES AND HOW THEY ACT

RATIONALE

In previous chapters it has been shown that Mendel's work established the existence of hereditary determiners (genes), and that the work of Sutton and Bridges demonstrated beyond doubt that the genes are located on chromosomes. The next important questions are, "What is a gene? How does it act?"

The answers to these questions begin with the study of the pneumococcus bacillus. Fred Griffith, in 1928, noticed that live pneumococcus bacteria without capsules could be induced, in some cases, to form capsules in the presence of an extract of dead pneumococci with capsules. It was thus obvious that living pneumococcus cells could be transformed, in the presence of some substance from the capsule-forming cells. The work of Avery, MacLeod, and McCarty showed this transforming principle to be DNA. Later work and interpretation indicated that here was a case where genes can be extracted from one organism and be made to enter another. As the extract contained only DNA, it was reasonable to conclude that the gene is DNA.

Further work with microorganisms, specifically with viruses, showed that only the DNA of a virus enters the host cell and causes it to make more viruses; the protein coat of the virus does not enter the host cell and thus is not active in the reproduction of the virus. The DNA is the genetic material of the virus.

The chemical structure of DNA has only recently been elaborated by the work of Watson and Crick, who created a model of a DNA molecule showing the relationship of its purines and pyrimidines to the sugar and phosphate portions. As is so often the case, the creation of the model posed additional problems, the chief of which is how there can be a quantitative and qualitative division of DNA molecules, each a double helix with its distinctive part hidden away in the center. Investigation indicated that the strands of the double helix become separated much as a zipper is opened, and that new nucleotides of the proper kind are added to the separated strands, until in place of the one molecule of DNA, there are two. As each new DNA molecule is a replica of the original, the process of making this exact copy is called "replication." Thus, the Watson-Crick model made possible an explanation of how a huge, complicated molecule can be copied exactly. That this explanation, or postulated mechanism, is in fact the correct one has been strengthened by the work of Meselson and Stahl, who used a heavy isotope of nitrogen in preparing nucleotides for incorporation into DNA.The actual pattern of incorporation was observed (by analysis of the nucleotides with heavy nitrogen) to follow the anticipated pattern of the hypothetical mechanism.

Knowing that a gene is DNA and knowing its molecular configuration still does not answer the problem of how genes act. What causes them to pass on replicas of themselves? How, by their action, do they control each and every step of an organism's development and metabolism? It is to the second of these questions that the chapter next turns, to report on the experiment that first provided insight into the way genes work.

The work of Beadle and Tatum on *Neurospora* led the way to a preliminary understanding of gene action, in which genes control biochemical re-

actions within the cell by controlling the production of enzymes. It was previously known that enzymes make possible the addition or removal of specific groups of atoms from molecules that participate in the essential activities of plants and animals. Now it was shown that mutations could cause certain enzymes normally found in cells not to be produced, thus blocking the biochemical steps controlled by these enzymes.

Students may at first question why scientists would work with molds, but they will understand why when they learn that the discoveries of gene-enzyme relationships in *Neurospora* led to their prediction and confirmation in humans (for example, in sickle-cell anemia). With the genes' role in controlling the biochemical activities of the cell now being unraveled, another question was raised. How does the gene exert its control over the enzyme? In answer to this question, it has been shown that by means of messenger RNA, transfer RNA, and ribosomes, the order of amino acids being synthesized by a cell is specified. The hereditary code contained in the DNA molecule is suc' that it allows for a communication of directions for the synthesis of proteins, especially enzymes, and thus exerts an indirect control over all chemical reactions of the cell.

In considering the role of genes in development, it becomes apparent that genes alone do not constitute the entire story of development of the organism. The nucleus and its contained genes work in conjunction with cytoplasm, perhaps in much the same way that heredity works in conjunction with environment.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 572)

1. Two different roles of genes are: (a) ability to pass on replicas of themselves; and (b) to control, by their actions, each step of an organism's development and metabolism.
2. The problem of gene action may be studied in different ways. One way might be to study the embryonic development of individuals with different genotypes to determine when the first visible beginnings of their differences occur—such visible differences are surely preceded by chemical differences, which can then be pinpointed for study. A second method is to investigate the way in which genes act in individual cells in early stages of development or in organisms with very simple structures. Thus we may discover the biochemical differences when a certain allele is present or absent.
3. The pink bread mold *Neurospora* develops a white mat of hyphal strands and produces tufts of pink or orange monoploid spores on stalks that rise above the growth medium. Reproduction is by means of these spores. The life history is similar to that of molds in general.
4. *Neurospora*, as an experimental organism for genetics, grows luxuriantly in a test tube on a minimal medium of salts, some table sugar, and biotin. Though it does not appear to be very complex structurally, it is quite complex biochemically, as it synthesizes complex proteins, carbohydrates, fats, and vitamins from a simple substrate. The fact that it is easy to obtain, simple to raise, responsive to radiation, and can be relatively easily analyzed for its biochemical constituents makes it an excellent organism for genetic study.
5. Once the one gene-one enzyme relationship was stated, many workers began studies of mutant types of *Neurospora* to determine whether a particular enzyme was absent or reduced in activity once a specific

biochemical step blocked by mutation had been identified. Many such cases were found, which tended to verify the one gene-one enzyme relationship.

6. An example of a one gene-one enzyme relationship in man is a special type of low mentality (a form of idiocy). It has been shown to be the result of the blockage of a single biochemical step necessary for the conversion of phenylalanine to tyrosine. The specific enzyme necessary for the conversion has been identified in the liver of normal individuals; it is absent from the liver of persons affected by this type of idiocy. Another example is sickle-cell anemia, which involves the simple substitution of a valine unit for a glutamic acid unit at one point in the hemoglobin molecule.
7. The DNA of the nucleus controls the synthesis of a specific complementary RNA known as messenger RNA. The messenger RNA passes into the cytoplasm and becomes associated with the ribosomes. In effect, it becomes a template for protein synthesis. Transfer RNA, another sort of RNA already free in the cytoplasm, picks up individual amino acids and transfers them to the messenger RNA template. A different form of transfer RNA exists for each of the twenty or so amino acids. The template determines the specific order of linkage of amino acids in polypeptides, from which the proteins are made. The evidence on which such a system is postulated is twofold: (a) cells with the most RNA are generally the ones most actively engaged in protein synthesis, and (b) ribosomes of the cytoplasm contain most of the cellular RNA. The incorporation of radioactive atoms into molecules has made it possible to trace the main steps of protein synthesis.
8. One of the unsolved problems of gene action is how different cells become specialized in development to do different things, if every gene is present in every cell. Why do some genes seem to produce their effect immediately, while others (such as those associated with sexual maturity and baldness) manifest themselves only later in life? And why do some genes fail to show their effect under certain environmental conditions? (If fruit flies with genes for vestigial wings develop at high temperature, their wings are almost normal in length.) We still need to find out the primary effect of each gene in order to properly appreciate the mechanism of gene action.
9. In the experiments with *Acetabularia*, there is evidence for the nuclear control of developmental processes. In the case of fertilized sea urchin eggs that have been separated along normal cleavage lines at the four-celled stage, each of the four cells results in a small but complete larva. Both these experiments indicate nuclear control in the formation of new parts or new individuals. If, however, unfertilized sea urchin eggs are sectioned across their axes and then both halves are fertilized, both of the resultant half embryos then die regardless of which half contained the egg nucleus. In comparing the two different sea urchin experiments, we conclude that the cytoplasm must indeed affect and limit what the genes in the nucleus are able to do in controlling the path of development.
10. In *Acetabularia*, the nuclei control the shape of the cap. Therefore, if two nuclei of different species were combined in the same plant, one might expect either a blending of genetic control to produce an intermediate shaped cap (particularly if many genes were involved), or the dominance of the genes in one or the other of the two nuclei.

11. The experimental evidence that links DNA with heredity begins with transformation in pneumococcus bacteria; a DNA-containing extract causes nonencapsulated bacteria to be transformed into capsulated bacteria. Evidence that DNA is the hereditary material of viruses is supported by the work of Hershey and Chase. All the evidence so far accumulated in experiments on organisms from bacteria to complicated animals and plants supports the view that the hereditary instructions in the cell are carried in nucleic acid molecules that in most instances are DNA. The evidence appears conclusive because of the numerous experimental proofs offered.
12. The fact that the mold *Penicillium* does not require biotin in its culture medium does not suggest that biotin plays no role in the metabolism of the organism. It may be that *Penicillium* is capable of synthesizing its biotin from the simple organic molecules of the media on which it is growing.
13. Human heredity is difficult to study on an experimental basis partly because of the length of time between generations, but mainly because of the general feeling against using humans as experimental organisms for reproductive studies. The present knowledge of human heredity is derived mainly from case history and pedigree techniques, which are subject to error because of the inadequacy and inaccuracy of records.
14. The genetic mechanisms of all organisms studied thus far seem to be tied to DNA. In the absence of any evidence to the contrary, information gained about DNA in simpler organisms can be expected to be applicable to higher living forms. Limited experimental confirmation, from molds to man—as in the ornithine cycle, for example—supports the validity of utilizing with higher organisms the results of experimentation on simpler forms.

REFERENCES

Useful books:

Allen, J. (ed.), 1962. *The Molecular Control of Cellular Activity*. McGraw-Hill, New York

Asimov, I. 1963. *The Genetic Code*. Signet, New York

_____ 1961. *The Well Springs of Life*. Signet, New York

Kersaint, G. (ed.), 1962. *Deoxyribonucleic Acid: Synthesis, Structure and Function*. Pergamon, New York

Kornberg, A. 1962. *Enzymatic Synthesis of DNA*. John Wiley & Sons, New York

Sutton, H. 1961. *Genes, Enzymes, and Inherited Diseases*. Holt, Rinehart and Winston, New York

Articles in journals:

Benzer, S. 1962. "The Fine Structure of the Gene." *Sci. Am.* 206 [1] 70

Crick, F. 1962. "The Genetic Code." *Sci. Am.* 207 [4] 66

_____ 1954. "The Structure of the Hereditary Material." *Sci. Am.* 191 [4] 54

Horne, R. 1963. "The Structure of Viruses." *Sci. Am.* 208 [1] 48

Hotchkiss, R. D., and E. Weiss. 1956. "Transformed Bacteria." *Sci. Am.* 195 [5] 48

Hurwitz, J., and J. Furth. 1962. "Messenger RNA." *Sci. Am.* 206 [2] 41

Ingram, V. 1958. "How Do Genes Act?" *Sci. Am.* 198 [1] 68
Isaacs, A. 1963. "Foreign Nucleic Acids." *Sci. Am.* 209 [4] 46
Zinder, N. 1958. "'Transduction' in Bacteria." *Sci. Am.* 199 [5] 38

FILMS

Genetics, Part VI: *Cytoplasm and Differentiation*, No. 10, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Genetics, Part VI: *Biochemical Genetics*, No. 11, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Genetics, No. 38: *DNA Structure and Replication*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill
Genetics, No. 39: *Biochemical Genetics I*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill
Genetics, No. 40: *Biochemical Genetics II*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill
Genetics, No. 41: *Gene Structure and Gene Action*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Chapter 33 GENES IN POPULATIONS

RATIONALE

This chapter focuses attention upon the genetics of populations as a whole, rather than of individuals. There are numerous complications in population genetics, primarily because it is impossible for the geneticist to know everything he should know about populations if he is to reach accurate conclusions.

All the genes that the members of a population contribute to the next generation constitute a gene pool, and any offspring represents a one-member sample drawn from this gene pool. The population geneticist first defines the population with which he is working, then takes as large and as random a sample as possible. This random sample will contain a definite ratio of the alleles for a given trait, presumably in the same ratio as for the entire population. As the frequency of the different genotypes remains the same from generation to generation, the population is in equilibrium (providing there are no upsetting influences, such as mutation or selection). This equilibrium can be expressed mathematically through the Hardy-Weinberg Principle. At first, this principle may seem formidable to some students, but upon analysis it is found to be based on simple mathematics and elementary algebra. Not all students will easily master the Hardy-Weinberg Principle and its application, but every class should have some students who not only master its use but actually enjoy the calculations involved. Using the Hardy-Weinberg Principle, the geneticist can determine the frequency of a given allele in a population, if he knows accurately the relative proportion of only one of the phenotypes in the population. Once the frequency of alleles is found, all other information desired can be determined. A knowledge of population genetics gives us one basis for dealing with prolems in which the welfare of the entire population is involved.

Though the assumption is made that populations are in equilibrium, we know that their gene frequencies are in a process of slow transition; the

primary factors causing gene frequency to change are mutation, natural selection, mating preference, isolation, immigration, and emigration. Gene pools in transition are characteristic of an evolving population, and when gene pools of two populations become different enough, the populations may no longer be able to interbreed. This genetic isolation, which takes a long time to come about, is basic to the production of new species and essential in the process of evolution.

The students become increasingly familiar with the phenomenon of natural selection, heretofore introduced only briefly. To some extent they also become familiar with the process of artificial selection in the breeding of domestic animals and plants. The perfection of the techniques of artificial insemination has added new dimensions to the phenomenon of artificial selection; it has been an important device for the breeding of desirable animal stocks.

Once again, as in Chapter 32, the difficulties of studying human genetics are emphasized. Some of these difficulties are the long span of years in human generations, the impossibility of accurately measuring many human characteristics, uncertainty concerning whether or not certain traits are inherited, antipathy toward using planned matings, and a relatively small number of offspring per family. Despite these handicaps to the human geneticist, advances are being made in understanding human heredity. Our knowledge of blood types, hemophilia, color blindness, baldness, diabetes mellitis, eye color, skin color, height, weight, resistance to tuberculosis, and similar traits is at least the beginning of an understanding of problems in human heredity.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 587)

1. The main problem that a population geneticist faces is that he has no control over the crosses that are made. Matings occur at random and from the frequencies of phenotypes he must reach conclusions about the gene pool. The geneticist must also consider the fact that some members of the population do not contribute children to the next generation because of age or other factors, that mating in human populations is preferential, and that some parents have more children than others. These are only a few of the problems encountered, others of which include the impossibility of studying all members of large populations, and the accompanying problem of selecting samples that will be representative.
2. A simple model of a population eliminates the complications with which one cannot deal (such as the absence of random matings). The planning of a model is supported by much data from human populations, and can be refined as more data are accumulated. A simple model, therefore, becomes very useful for biological studies in offering a workable mechanism for dealing with an otherwise insoluble problem.
3. The assumptions made for a population model are: (a) all members of the population mate and produce offspring; (b) all matings produce the same number of offspring (which reach maturity); and (c) mating is at random.
4. In sampling a population, the population geneticist takes a sample that is as large as possible and that is selected at random. In this way he chooses a sample that is thought to be representative of the entire population. The assumption is made that the sample population con-

tains traits in the same proportion as that in which they occur in the entire population.

5. The term gene pool describes all of the genes that the members of a population may contribute to the next generation.
6. The Hardy-Weinberg Principle helps clarify the nature of the gene pool from generation to generation by giving us a mathematical procedure for determining the frequencies of the zygote genotype in each generation.
7. In human populations, the more we know about the distribution of alleles that affect such things as health, intelligence, and other abilities, the more success we are likely to have in coping with the problems that involve the welfare of the entire population. (For example, sterilization of individuals with abnormally low intelligence is permitted in some states, but not in others.)
8. The major factors that cause gene frequencies in the population to change are: mutation, natural selection, isolation, and emigration and immigration.
9. Artificial selection is selection by man, as opposed to natural selection (selection by the natural environment). For organisms of great importance to him, man selects the purebreds or variants or mutants that are allowed to produce the next generation. The use of artificial selection has led to sheep with heavier coats, cows that give more milk, wheat plants that have more grain in the spike, hybrid corn, and many other organisms with desirable traits.
10. At the outset, plans to improve human heredity face difficulties because: (a) people cannot agree upon what direction of change should be considered "improvement"; (b) very little is presently known about human inheritance, making it difficult to assess hereditary probabilities; and (c) regarding even those few traits that are agreed to be both largely hereditary and highly desirable, the idea of "planned marriages" rarely is given serious consideration, in the face of emotional inclinations otherwise.
11. The population is 20.5 percent homozygous dominant, 49.6 percent heterozygous, and 29.9 percent homozygous recessive. Rounding off the square root of .30 to .547, the students will probably solve the problem as follows:

	.453T	.547t
.453T	20.5209	24.7791
.547t	24.7791	29.9209

12. The frequency of the r allele is 40 percent (.4). The frequency of the R allele is 60 percent (.6). Thirty-six percent of the population ($.6^2$ = .36) is homozygous dominant, 48 percent (2 × .4 × .6 = .48) heterozygous, and 16 percent ($.4^2$ = .16) homozygous recessive. The frequency of matings between RR husbands and rr wives is 5.76 percent [♂ RR (.36) × ♀ rr (.16) = .0576 or 5.76%]. The frequency of matings between Rr husbands and rr wives is 7.68 percent [♂ Rr (.48) × ♀ rr (.16) = .0768% or 7.68]. As all the babies of the first mating are Rr, their frequency in the population is 5.76 percent. Only half of the babies in the second mating are Rr; their frequency is 3.84 percent (1/2 × 7.68%). Therefore, the total frequency of Rr babies in rr mothers is 9.6 per-

cent [5.76 Rr + 3.84 Rr = 9.6%]. This value is very close to the 10 percent figure given in the text. The discrepancy is due in part to the fact that the text uses a figure of 85 percent for Rh-positive individuals while this problem assumes only 84 percent.

REFERENCES

Some of the statistical material of Chapter 13 (page 402 of the *Teachers' Handbook*) may be useful to the teacher when dealing with the quantitative aspects of genetics.

Useful books:

Boyer, S. 1963. *Papers on Human Genetics*. Prentice-Hall, Englewood Cliffs (N.J.)

Carson, H. 1963. *Heredity and Human Life*. Columbia University Press, New York

Dunn, L. 1959. *Heredity and Evolution in Human Populations*. Harvard University Press, Cambridge (Mass.)

Gardner, E. J. 1960. *Principles of Genetics*. John Wiley & Sons, New York

Pontecorvo, G. *Trends in Genetic Analysis*. Columbia University Press, New York

Stern, C. 1960. *Principles of Human Genetics*, 2nd ed. W. H. Freeman, San Francisco

FILMS

Genetics, Part VI: *The Treasury of Human Genes*, No. 12, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *Blood Groups, Skin Color and Gene Pools*, No. 7, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, No. 24: *Genetics of Mendelian Populations*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Chapter 34 DARWINIAN EVOLUTION

RATIONALE

Just as evolution provides a synthesis of biological knowledge, so this chapter on Darwinian evolution provides a synthesis of the materials presented thus far in this course. Here the students will encounter the application of many of the facts and principles studied earlier to the overall pattern of continuity through evolution.

By now the word evolution should be a part of the students' vocabulary, as the term has been encountered many times before. Students have become familiar with many evidences of evolution in the chapters on plants and animals, and they are aware of the possible mechanisms of evolution as presented in the chapters on genetics.

In the beginning of this course, the chapters dealing with the unity of life (Part I: Chapters 1-8) stressed the fact that there is a common group

of principles applicable to all living organisms, whether they be microorganisms, plants, or animals. Unity of living materials and the significance of this unity were elucidated many times. The coverage of fungi and of plants in Chapters 12-17 was essentially an evolutionary one; and, in the animal section of the text, the development of various systems through the comparative approach laid the groundwork for much that appears in this chapter. The chapters on genetics laid the basis for understanding the mechanisms of change that are the essence of evolution, and now this chapter serves to bring together the knowledge acquired thus far for the comprehension of the process of evolution.

The study of evolution begins with an account of the classical work of Charles Darwin. While our concepts of evolution have changed since the time of Darwin, the essential features of the phenomenon of natural selection, which is the central theme of Darwinian evolution, remain much as he developed them. They are: (1) the presence of individual hereditary variations, (2) the tendency for a population to increase in numbers, (3) a subsequent competition for the needs of life (a struggle for survival), and (4) a difference in the contribution that different types of individuals make to succeeding generations, leading to a gradual increase in numbers of individuals best adapted to the environment and a decrease in numbers of other individuals. Animals thus become adapted to their environments by natural selection, operating upon hereditary variations over long periods of time.

The students should know that Darwin was not the first evolutionist; indeed, evolutionary thought can be traced back approximately 2500 years. Today Darwinian evolution is interpreted in terms of our increased knowledge of heredity and of environmental influences. In addition, experimental approaches to evolution, regarding adaptation and selection, have contributed new evidence concerning the evolutionary process.

Darwin summarized his evidences under five principle categories: (1) evidence from inheritance and breeding; (2) evidence from geographical distribution; (3) evidence from the geological record (fossils); (4) evidence from unity of plan and diversity of pattern (especially homologies); and (5) evidence from embryology and rudimentary organs. These five evidences are the ones by which students will judge the soundness of Darwin's approach. Subsequent experimental evidence, unknown to Darwin, has served to substantiate the theory of evolution.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 610)

1. Everything that organisms are reflects the evolutionary process. All the diversity in life today is the result of evolution, and even life itself evolved from nonlife, beginning with the evolution of the first organic compounds from their inorganic environment. Every other fact and principle of biology is secondary to evolution.
2. The factors Darwin emphasized as the major ones in bringing about evolutionary changes were: the presence of individual variations, the tendency of a species to increase in numbers of individuals, the struggle for survival among members of a species, and the difference in the contribution that different types of individuals make to succeeding generations. Or, more briefly, the major factors are variation and natural selection.
3. The entire evolutionary process, and especially the "struggle for sur-

vival'' and the difference in rate of survival and reproduction among the participants, Darwin called natural selection. In essence, Darwin's concept was one of ''the fit live to reproduce; the less fit perish.''

4. Lyell influenced Darwin by describing all the known evidence for concluding that the earth had been in existence for a long period of time, during which many changes had occurred. Reading the work of Lyell caused Darwin to wonder what the earth was like thousands of years ago, and what kinds of organisms existed in early times.
5. On the voyage of the *Beagle*, Darwin was impressed by the tremendous numbers of living things he encountered and by the small chance for survival of any new individual. He became conscious of the variation among animal populations and was particularly challenged by the diversity among the animals of the Galápagos Islands. His voyage thus provided him with data that proved useful in his formulation of the evolutionary theory.
6. In artificial selection man picks the individuals that will reproduce the following generations. His choices are based on his desires for increasing the frequency of occurrence of particular traits such as richness of flavor in fruits, speed in horses, disease resistance in wheat, etc. In natural selection, on the other hand, those individuals that are best adapted to a particular environment are the ones to survive and reproduce the following generations (regardless of whether these adaptations are advantageous to man). Thus, both processes involve selection of a breeding population, but the selective mechanisms in the two processes are different.
7. Lamarck's explanation of the factors responsible for evolution involved the ''needs'' of the organism, the use and disuse of certain parts of the body in trying to meet these ''needs,'' and the inheritance of modified (acquired) characteristics (where ''practice'' could make them more nearly ''perfect'').
8. While the environment selects genotypes to be preserved and in some instances influences the expression of the genotypes, it can neither contribute genes to, nor delete genes from, an organism. In an accident, for example, a person may lose an arm or leg, but this environmental modification is not passed on to the offspring. The work of Weismann, involving the amputation of tails of mice over many generations, did not induce any perceptible change in the tail lengths of newborn mice.
9. Light-colored animals in dark-colored environments are more conspicuous than dark-colored animals. Therefore, light-colored animals are more obvious to predators, and they are thus more likely to be removed from the population by the process of natural selection. Similarly, dark-colored animals in light-colored environments would be selected against by the process of natural selection. The geographic locations of deer mice and birds of various colorations are in keeping with this explanation.
10. The advantages of using microorganisms for studies of natural selection are that they are hardy, they grow rapidly, they reproduce rapidly, they have large numbers of offspring, and they can be maintained easily in a small space. Of great importance is the fact that many generations can be observed in a relatively short span of time.
11. According to natural selection, the extinction or disappearance of a species of organism occurs because the species becomes progressive-

ly less well adapted to changing environments and proves incapable, ultimately, of reproducing enough of its own kind to ensure survival. The number of organisms in the species becomes smaller and smaller in succeeding generations, thus aggravating the process and eventually leading to extinction.

12. Natural selection is a creative force in the sense of selecting progressively better adapted organisms for specific environments. It is not a creative force in the sense of adding new genetic material to a species.
13. If adaptations are lost by a species over a long period, the population becomes successively less well adapted to the particular environment. Ultimately, such loss of adaptation leads either to extinction or to emigration to a new environment to which the population is better adapted.
14. On the basis of the concept of the unity of life, we would expect to find the same forces operating on all levels of taxonomic organization, from species to higher categories. Evidence from geographic distribution, inheritance, fossil remains, homology, morphology, embryology, and vestigial organs supports the statement that higher categories arise as a result of the same processes as do species.
15. Fossil remains are studied to discover trends in evolution and to find out which fossil animals were ancestral to others. The existence of the fossil record, and our ability to date fossils, has made it possible to trace changes in organisms over hundreds of millions of years.
16. The presence of homologous structures and vestigial organs indicate relationships between groups of living organisms and their fossil ancestors. As homologous and vestigial structures are modifications of a basic structural pattern, they provide evidence of various degrees of evolutionary change.
17. A vestigial organ is an organ that has been reduced (by evolution) in both size and function. Examples of vestigial organs in man are the tailbone, ear muscles, and appendix, all of which presumably are no longer being selected for. The presence of vestigial organs indicates a relationship between the animals possessing them and other animals possessing these structures as functional organs. Vestigial organs are thus another structural evidence of change through time
18. Today the similarities of embryological development among vertebrates are interpreted to mean a relationship among groups—not recapitulation in the sense of "ontogeny recapitulates phylogeny." In related groups, similarities of early embryological development followed by differences in later stages of development indicate divergent evolution from a common ancestor.

REFERENCES

Chapter 11 (page 331) of the *Teachers' Handbook* deals with dating by radioactive isotopes and may prove a valuable resource to the teacher in discussing methods of determining the age of fossils.

Useful books:

Blum, H. F. 1962. *Time's Arrow and Evolution*. Harper Torchbooks, New York

Cain, A. 1960. *Animal Species and Their Evolution*. Harper Torchbooks, New York

Dodson, E. 1960. *Evolution: Process and Product*. Reinhold, New York
Mayr, E. 1963. *Animal Species and Evolution*. Harvard University Press, Cambridge (Mass.)
Merrell, D. 1962. *Evolution and Genetics*. Holt, Rinehart and Winston, New York
Montagna, W. 1959. *Comparative Anatomy*. John Wiley & Sons, New York
Moore, J. 1963. *Heredity and Development*. Oxford University Press, New York
Ross, H. 1962. *Synthesis of Evolutionary Theory*. Prentice-Hall, Englewood Cliffs (N.J.)
Sheppard, P. *Natural Selection and Heredity*. Harper Torchbooks, New York

Articles in journals:
Gilliard, E. T. 1963. "The Evolution of Bowerbirds." *Sci. Am.* 209 [2] 38
Glaessner, M. 1961. "Pre-Cambrian Animals." *Sci. Am.* 204 [3] 72

FILMS

Life, Time and Change, Part X: *Rocks and the Record*, No. 1, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Life, Time and Change, Part X: *Darwin and Evolution*, No. 2, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Life, Time and Change, Part X: *Natural Selection and Adaptation*, No. 4, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Life, Time and Change, Part X: *Species: Stability and Change*, No. 6, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Hunting Animals of the Past, 1951, (sd, c, 22 min), p or r, Nebraska
Journey into Time, 1960, (sd, b&w or c, 14 min), p, Sterling

Chapter 35 THE MECHANISMS OF EVOLUTION

RATIONALE

In the preceding chapter, which dealt with Darwinian evolution, it was pointed out that before evolution can occur there must be a variety of heritable characteristics, from among which natural selection identifies the particular characteristics that give organisms the greatest chance for survival and reproduction. The requisite variability originates in two main ways: first, by mutation, and second, by the constant recombination of different alleles in sexual reproduction.

Mutations are both rare, and, for the most part, harmful. A mutant form of any particular gene will be found, on the average, about one in one hundred thousand germ cells. What makes mutation an important source of the necessary raw material for evolution is not so much its frequency of occurence as the great number of individuals and germ cells in which mutations can occur—thousands of genes per germ cell and perhaps millions or billions of individuals producing germ cells in each generation of a species. This fact, coupled with the many generations that have occured over the

span of evolutionary time, leads to an impressive number of mutations in total, even though individual mutations may be rare. Even in man, if we assume 20,000 genes per gamete, the chances of a freshly mutated gene are about two in five. Mutation can be speeded up by means of X rays, as shown by Muller's work with *Drosophila*.

The fact that most gene mutations are harmful in the environment in which the organism finds itself is somewhat masked by the fact that most mutant genes are recessive and do not express themselves in the heterozygous condition. Consequently, harmful genes are often undiscovered for many generations, and as recessives, they can persist indefinitely in populations, since they will not be selected against in heterozygous individuals. If and when the environment changes so much that a gene formerly considered harmful becomes beneficial to the organism, its existence may well account for the survival of the species.

Genetic recombination is as necessary as mutation in providing the variability upon which natural selection can operate. From earlier work in the course, students are familiar with the fact that offspring of sexually reproducing animals and plants show greater variability than offspring of asexually reproducing organisms. The examples in this chapter serve to reinforce and elaborate this idea.

The evolutionary process is based mainly on mutation, recombination, selection, migration, and isolation. In addition, the size of populations is of consequence because, while natural selection guides evolutionary change in large populations, in small isolated populations random genetic drift may lead to nonadaptive characteristics. All of the listed factors except isolation produce changes within a species; isolation is a requisite for the origin of new species. Isolation may be a factor of time, of geographic separation, or of genetic differences.

Reproductive or genetic isolation almost always begins by physical separation of parts of a population. Once this separation occurs, natural selection may act in different ways on the two populations, ultimately leading to reproductive isolation, which takes a number of forms. These include failure to produce hybrids, production of hybrids that die when young, and production of hybrids that are sterile. The mating instincts of the different populations may be such that individuals do not cross in nature even though they may form vigorous, fertile hybrids if crossed artificially.

While the processes described thus far in this chapter usually require many thousands of years to create new species, an almost instantaneous new species is formed when polyploidy occurs. In such cases, meiosis has failed to take place before gamete formation, and the offspring have twice (or three or four times) the diploid number of chromosomes. The resultant polyploid species conforms to our definition of a distinct new species—a group of individuals that can breed with each other but do not usually breed with individuals of other species. Colchicine has been very effective in doubling the chromosome number in cells exposed to it. Through its use, artificial production of polyploid species by man has become possible.

The same factors that operate in the formation of new species also operate in the formation of genera and larger groups. Two additional factors also act in the evolution of larger groups: (1) the multiplication of populations having a particular combination of genetic characteristics; and (2) the extinction of intermediate populations. The comprehension of these factors is necessary for the understanding of the mechanisms of evolution.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 632)

1. The principal mechanisms of evolution are mutation, recombination, and natural selection.
2. The fact that mutations are extremely rare, and that they are usually harmful, would tend to suggest that they might not provide the raw material for evolution.
3. In 1927, H. J. Muller discovered that X rays could be used to induce mutations in *Drosophila*. He studied and analyzed many X ray-induced mutations. In fact, it is he who discovered that by far the greatest number of mutations are harmful.
4. A beneficial mutation is rare, but two factors enhance the probability of its occurrence. First is the number of genes per organism—usually many thousands. Second is the number of organisms in all the populations of a given species—usually millions or billions. In large populations even rare events are likely to occur.
5. Most mutations are recessive. Hence whether they are harmful or beneficial, they usually show their effect only in the homozygous condition. In the population, a mutation is "selected for" or "selected against" when it affects the phenotype, but not when it is masked by a dominant gene in heterozygous individuals. Thus recessive mutant genes of a harmful nature may persist in the heterozygotes of each generation.
6. A mutation harmful in one environment may be beneficial in another. For example, a mutation that lowers tolerance to heat may be harmful in a warm climate, but beneficial if the animal were to migrate to a cooler climate or if the temperature of the immediate environment were to become lower.
7. The purple European columbine is adapted to being pollinated by the European bumblebee, while the American red columbine of the West Coast is adapted to being pollinated by hummingbirds. A red columbine with a curved spur would not easily yield food to hummingbirds, and soon the hummingbirds would no longer visit the flowers and pollinate them. Correspondingly, a purple columbine with a long spur would for a similar reason not be pollinated by the bumblebee. Therefore, the two postulated combinations would be harmful, while the naturally occurring ones are beneficial. Assuming that at least one of the flower variations, perhaps both, are mutants, we have an example of mutations that are beneficial or harmful depending on the relationship to pollination by a particular animal.
8. In organisms that reproduce sexually, crossing over, segregation, and independent assortment reshuffle the genes and increase tremendously the genetic variation of gametes. In many crossbreeding populations, thousands of gene combinations already exist. Each mutation increases the number of existing gene combinations by an exponential factor.
9. The results of Johannsen's experiment showed that, after the first generation, selection had no effect in either increasing or decreasing bean size. He assumed that all the size differences between beans grown in the same field in the second and later generations were due to environmental conditions. He thought that the homozygous pure line was a typical genetic constitution of organisms in nature and therefore concluded that natural selection could not be important in evolution.

10. The difference between Johannsen's results and those of the Illinois agronomists are due to differences in the amount of genetic variability present in the populations before selection began (and not to differences in mutation). As garden beans are self-pollinating, they have become genetically homozygous at all or most of their gene loci. Hence, the different plants of any pure line are practically identical. Corn, on the other hand, is normally cross-fertilized, and corn plants are heterozygous for many pairs of allelic genes. Different individuals of the same variety of corn differ from each other in gene content much more than do beans of the same variety.
11. A species consists of a genetically isolated population—that is, a population consisting of individuals that: (a) can interbreed with one another, or at least are related by intermediate varieties that can interbreed with varieties at the genetic extremes; and (b) cannot, or do not, interbreed with any other types of organisms and produce fertile offspring.
12. Barriers to crossbreeding include: isolation by time, geographic isolation, and genetic isolation. Genetic (reproductive) isolation takes the following forms: (a) failure to form fertile or viable hybrids; (b) the formation of vigorous but sterile hybrids; (c) mating instincts that discourage individuals of different species from crossing in nature; and (d) breeding at different times of the year.
13. Reproductive isolation preserves the genetic identity of a population and prevents its distinctive characteristics from being shared, by crossbreeding, with other types of organisms.
14. A polyploid species is a species formed by an increase in the number of chromosome sets. One variant results from a cross between two existing species followed by a doubling of the chromosome number of the hybrid.
15. The kinds of variation that occur even in a single species, plus the types of evolutionary trends that are deduced from studies of the most complete series of fossils, provide strong evidence for the belief that the same evolutionary forces that operate today have guided evolution in the past. Furthermore, the difficulty that many experienced students of a group of organisms have in agreeing as to whether two species should be placed in the same genus indicates that the origin of genera and families of organisms is governed by the same forces as those responsible for the origin of species. Two additional factors in producing larger categories are the multiplication of populations having a particular combination of genetic characteristics and the extinction of intermediate populations.

REFERENCES

Invitation to Enquiry No. 13 (page 87) in the *Teachers' Handbook* illustrates practice in dealing with hypotheses (using the subject of natural selection) and may be used in conjunction with this chapter as well as with Chapter 34.

Useful books:

Grant, V. 1963. *The Origin of Adaptations*. Columbia University Press, New York

Ross, H. 1962. *A Synthesis of Evolutionary Theory*. Prentice-Hall, Englewood Cliffs (N.J.)

Simpson, G. G. 1961. *Principles of Animal Taxonomy*. Columbia University Press, New York
Wallace, B., and T. Dobzhansky. 1959. *Radiation, Genes, and Man*. Holt, Rinehart and Winston, New York

FILMS

Genetics, Part VI: *Mutation*, No. 8, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Genetics, Part VI: *Mendel's "Recombinations,"* No. 3, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Genetics, No. 28: *The Origin of Species*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill
Genetics, No. 29: *Interspecific Hybridization and Its Consequences*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill
Genetics, No. 22: *Spontaneous Gene Mutation*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill
Genetics, No. 23: *Mutagen-induced Gene Mutation*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill
Life, Time and Change, Part X: *Natural Selection and Adaptation*, No. 4, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Life, Time and Change, Part X: *Species: Stability and Change*, No. 6, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 36 THE ORIGIN AND THE HISTORY OF LIFE

RATIONALE

Evolution was first introduced to students in Chapter 1 (see Figure 1-3, text pages 8 and 9), and in Chapter 2 the first questions were raised about the origin of life. The initial understanding developed by Chapter 2 was that all life comes from pre-existing life and that abiogenesis is not a tenable doctrine. While this seems a satisfactory way of dealing with the origin of life at the introduction of the course, at least in the sense that origin may be taken to mean "the source of each new generation of living things," students are now much more knowledgeable and sophisticated in their approach to biology and are able to ask more searching and penetrating questions. This time the question, "Where did the animals and plants living today come from?" cannot be parried with the glib mention of "evolution," or with the previously satisfactory answer, "from pre-existing forms." The basic issue is how science can account mechanistically for the origin of life.

As science deals with material things, the explanations offered by scientists are necessarily mechanistic. We see, therefore, that there are three scientific possibilities about life's origin. The first, that life has been present on earth for all time, can be excluded because all available evidence indicates that the earth had a definite and lifeless beginning

about five billion years ago. The second, that life came from some other point in outer space, is not a satisfactory answer, for the question then becomes, "How did life originate on the planet from which it came to Earth?" In addition to not answering the basic question, the idea of the transport of living organisms through space seems highly unlikely. The third possibility seems much more likely, namely, that life arose on earth at some time in the distant past. The hypotheses on which this latter idea is based have some evidence in their favor, and yet it must be remembered that this particular exploration of the origin of life on earth is a hypothetical one which awaits much more evidence before it achieves the validity of the cell theory, the germ theory of disease, the theory of evolution, or the chromosome theory of heredity.

According to what has become known as the heterotroph hypothesis of life's origin, the atmosphere of the primitive earth contained water vapor, methane, ammonia, and hydrogen. Under certain conditions, molecules of these compounds must have combined to form organic compounds. As water condensed and built up the earth's seas, a great many organic compounds, some of which could be expected to react with one another, would have come to be in solution in the hot waters of that far-off time. Increasingly complex molecules would have formed, until at some point in chemical evolution, molecules that were self-producing could have formed. This would have been the point at which life started.

The work of Miller and Urey indicates that water, methane, ammonia, and hydrogen in the presence of electrical discharges combine to form amino acids, the structural units of proteins. Sidney Fox's experiments show how these amino acids could form polypeptide molecules. Melvin Calvin, in still other experiments, has demonstrated how some of the simpler molecules—the same ones Miller and Urey worked with—could have formed not only amino acids and sugars, but even purines and pyrimidines. Thus, there is some evidence that simple molecules can combine into organic ones that are self-producing. Such self-producing molecules in the ancient seas must have been able to obtain energy and building materials from other molecules in the solutions in which they were found; thus, they were heterotrophs.

The somewhat later evolution of the photosynthetic process would have represented a major step in the evolution of primitive organisms, as it enabled the development of autotrophs. Probably for a billion years, the dominant forms of life on earth were microscopic organisms, such as bacteria, molds, and the autotrophic algae. The evolution of the cell may have taken an extremely long period of time, but it obviously occurred. Then, from the evolved cell came the evolutionary advance of increased size and complexity of structure, as discussed in the chapters on animals and plants.

Although life, according to the reasoning just established, existed long before the time that has come to be called the Cambrian period, the fossil record of living forms becomes adequate only in the past 600 million years, or in other words, since the beginning of Cambrian times. Dating that long ago are fossil representatives of nearly every major phylum of animals living today. During and before the Cambrian period, algae and invertebrates dominated the seas, and chordates apparently appeared soon afterward, in the waters of the Ordovician period. Plants invaded the land, followed by animals. The first chordates to appear on land were in the Devonian period, and in Carboniferous times the reptiles arose from the

land-colonizing chordates. In the Mesozoic period the dominant reptiles gave rise to both birds and mammals, and by the end of this period reptiles had passed their evolutionary peak. They were followed in the Cenozoic by a proliferation of mammals. All this time the higher plants had been evolving. The flowering plants appeared before Cenozoic times and gradually became the dominant terrestrial plants.

This panorama of life from its origins in the primordial seas to the eventual development and dominance of mammals and flowering plants on the land should give students the beginnings of an understanding of the changes that have taken place on the face of the globe and in its living organisms over vast eons of time.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 656)

1. It is unlikely that life arrived on earth from some other planet because the extremes of cold in outer space, coupled with excessive radiation and the lack of atmosphere, could not be tolerated by any known form of life. Furthermore, the frictional heating of meteors, as they enter the earth's atmosphere, would be enough to kill any organisms that adhered to them in their journey through space.
2. Conditions on the primitive earth served to heat it immensely. The atmosphere of today had not yet evolved. In the high temperatures, the primitive atmosphere of methane, ammonia, water vapor, and hydrogen could have been activated by lightning and ultraviolet radiation to produce organic compounds. As the earth cooled, water vapor condensed into pools, lakes, and oceans. The organic substances could have dissolved in the waters to form a "hot thin soup" of amino acids, proteins, and ultimately, other nitrogen-containing organic compounds that might have given rise to a system that could reproduce. In contrast, the earth today has a lower temperature and an atmosphere composed of nitrogen, oxygen, carbon dixoide, water vapor, and only traces of other gases.
3. By passing an electrical discharge through a mixture of methane, ammonia, water vapor, and hydrogen, Urey and Miller were able to create molecules of amino acids. As amino acids are the structural units of protein, the Urey-Miller experiments give some support for the chemical origin of life.
4. Fox heated to the melting point a mixture of 18 to 20 amino acids. After it cooled, he found that some of the amino acids had formed polypeptide molecules not unlike those characteristic of protein. Calvin showed that gamma radiation, acting on a mixture of methane, ammonia, hydrogen, and water vapor, produces molecules of amino acids and sugars, as well as some tentatively identified purines and pyrimidines. As the latter are essential to the formation of ATP, DNA, and DPN, Calvin's experiment adds further support for the chemical origin of life.
5. Fossil remains of the early forms of life are absent for two main reasons: first, early animals and plants were probably small and had soft bodies that decayed and left few or no traces; second, the sedimentary rocks in which the earliest forms of life may have been trapped have been so altered by heat and pressure that any fossils contained in them would have been destroyed.

6. Life is believed to have originated in the waters of the earth because water is an excellent solvent, an ideal medium of chemical reaction, and offers a relatively stable environment. Probably nowhere else could the first heterotrophs have found a usable supply of substances on which to feed—a supply brought to them by ocean currents and by diffusion.
7. The first recognizable types of organisms on earth were almost certainly unicellular or acellular heterotrophs that fed on dissolved substances in the ocean waters.
8. The uplifting lands of the Permian period (at the close of the Paleozoic) increased the variety of environments. In place of low continents covered with jungles and fairly even in climate, the scene included hills and valleys, swamps and deserts, and varied climates. During this period of gradually increasing dryness, the reptiles increased in numbers because their eggs could survive away from water. Similarly, the seed plants could invade the dryer regions and survive where other types of plants could not.
9. The major features of the Mesozoic era were a new outburst of reptilian evolution correlated with an increase in land areas.The earlier club mosses, horsetails, and ferns were gradually overshadowed by cycads, ginkgos, and conifers; the last period saw the rise of the flowering plants. The Age of Reptiles came to a decline at the end of the Mesozoic, but in the early and middle periods reptile stocks had given rise to mammals and birds.
10. The extinction of species weeds out the old and makes room for the new. Organisms that formerly occupied habitats disappear, and the habitats can then be filled by new and different organisms. Actually, the transition does not occur in 1, 2 order as the preceding sentence may imply. The two events are coeval: certain organisms die out as (and perhaps partly because) others evolve and take their place.
11. During the early part of the Cenozoic era, or the Age of Mammals, the greatest mountain systems of the present were born. These mountains modified wind patterns and rainfall, and influenced the formation of forests and deserts. Thus they had a marked effect on the environment in which mammals were developing.
12. The early part of the Cenozoic witnessed an explosive evolution of mammals; all the major groups known today were present. The angiosperms became the dominant terrestrial plants, and by the end of the era, the plants were essentially like those of today.
13. The vast coal deposits in Greenland can be interpreted as evidence that at one time Greenland was largely tropical and subtropical, for coal is the fossilized remnants of plants that grew in swamps.
14. There was an increasing differentiation of environments in the Permian period. The rising land and increasing variety of climates, many tending toward dryness, gave the reptiles a great advantage over amphibians, because reptilian eggs did not require a watery environment to develop into offspring.
15. There is no acceptable explanation for the extinction of the dinosaurs. A change of climate, a change of vegetation, a change in the environment, or increasing competition from mammals may have helped account for their extinction, but the primary reason remains one of the puzzles of paleontology.

REFERENCES

Useful books:

Andrews, H. 1961. *Studies in Paleobotany*. John Wiley & Sons, New York

Asimov, I. 1962. *The Chemicals of Life*. New American Library, New York

Ehrensvärd, G. 1962. *Life: Origin and Development*. Phoenix Books, Chicago

Ehrlich, P., and R. Holm. 1963. *Process of Evolution*. McGraw-Hill, New York

Fraenkel-Conrat, H. 1962. *Design and Function of the Threshold of Life: The Viruses*. Academic Press, New York

Johnson, W., and W. Steere. 1962. *This is Life: Essays in Modern Biology*. Holt, Rinehart and Winston, New York

Oparin, A. 1962. *Life: Its Nature, Origin, and Development*. Academic Press, New York

______ 1957. *The Origin of Life on the Earth*, 3rd ed. Academic Press, New York

Rush, J. *The Dawn of Life*. New American Library, New York

Young, J. 1962. *The Life of Vertebrates*, 2nd ed. Oxford University Press, New York

Article in journal:

Newell, N. D. 1963. "Crises in the History of Life." *Sci. Am.* 208 [2] 76

FILMS

Life, Time and Change, Part X: *Systematics and Plant Evolution*, No. 7, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Life, Time and Change, Part X: *Origin of Life*, No. 8, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Life, Time and Change, Part X: *Dinosaurs*, No. 9, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Life, Time and Change, Part X: *From Water to Land*, No. 10, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, No. 48: *Biochemical Origin of Terrestrial Life*, 1960, (sd, b & w, 30 min), p or r, McGraw-Hill

Hunting Animals of the Past, 1951, (sd, c, 22 min), p or r, Nebraska

Prehistoric Times: *The World Before Man*, 1953, (sd, b & w or c, 11 min), p or r, Coronet

Chapter 37 THE EVOLUTION OF MAN

RATIONALE

Charles Darwin's The Descent of Man, published in 1871, evoked investigations into the evolution of man. It must clearly be understood that neither Darwin nor any other reputable scientist has ever seriously considered that man "came from monkeys" or "descended from the apes." What has been said is that both man and apes evolved separately from some common ancient ancestor.

Our story of fossil man begins with the discovery of *Pithecanthropus erectus*, the Java man unearthed by Dubois. Java man, Peking man, Atlantic man, and other similar finds show the existence, between 600,000 and 350,000 years ago, of a primitive man able to invent and use tools. The recent discovery of *Zinjanthropus*, in Africa, extends known tool-making back to approximately 1,750,000 years ago. In 1858, another discovery, of an almost complete fossilized skeleton of *Oreopithecus*, dates the first known representative of the *family* of man—the Hominidae—at some 10 million years ago. Still farther back, the Miocene remains of *Proconsul* demonstrate the evidence of an early primate primitive enough to have preceded the divergence of ape and hominid lines.

Recently developed and quite accurate dating methods by which to determine the age of human fossils include the uranium-lead method, the potassium-argon method, the fluorine isotope method, and carbon-14 dating. Prior to the development of these methods, fossils of less than 600,000 years of age were dated from the glacial or interglacial rock strata in which they were found.

Mammals arose from reptilian stocks in the Mesozoic. The first primates evolved from a line of insectivorous shrews. Lemuroids, tarsiers, New World monkeys, and Old World monkeys arose from these early stocks. More than 25 million years ago, either in the late Oligocene or early Miocene, the ancestors of the apes and of man began evolving along separate lines. When we should speak of man as having appeared is uncertain, and strictly speaking, is a problem only of terminology. Toolmaking is now known to be at least 1,750,000 years old, but the first hominids to which the name man has definitely been assigned are the pithecanthropines—Java man and Peking man.

The fossil men we know most about are more recent. Just before the last glacial advance, Neanderthal man appeared in Eurasia and Northern Africa. The successor to Neanderthal man was Cro-Magnon man. Concurrently with the physical and mental development of man, his way of life and his level of culture gradually improved. Anthropologists interpret the invention and improvement of tools as evidence of early man's intellectual and cultural development.

Between 10,000 and 6,000 years ago, *Homo sapiens* devised clothes and learned new skills in foodgathering. The current races of man—Negroid, Caucasoid, and Mongoloid—are believed to have resulted from a long history of comparative isolation. Isolation extending back as much as 25,000 years is probably responsible for measurable differences between native peoples of different geographic locations. All races of man are similar in physical and biochemical characteristics and are comparable in native intelligence. Intelligence seems to be an individual rather than a racial trait, and "human nature" appears to be determined in large part by the cultural surroundings of individuals and groups.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 672-73)

1. Physical traits that seem to be especially characteristic of the human species include a broad pelvis, long legs, narrow-flat feet, erect posture, relatively unspecialized teeth, independently mobile arms ending in grasping fingers and opposable thumbs, a complex brain, a skull with its juncture to the spinal column relatively far forward, and a voice box linked to a speaking mouth. Man and other primates show numerous sim-

ilarities in structure and function, in the digestive, respiratory, reproductive, and other systems.

2. Among the specific anatomical details that man shares with his primate relatives are a flattened snout, stereoscopic vision, nails on all fingers and toes, and grasping hands.
3. Primitive tools found near fossil remains of man are interpreted as evidence of man's ability both to make and to use tools.
4. Authorities do not agree as to whether australopithecines should be classed with man in the family Hominidae or with the great apes in the family Pongidae. In either case, australopithecine fossils are important in the study of human evolution because they indicate the existence at a much earlier time than previously thought of a primate intermediate in position between man and the great apes.
5. There is uncertainty about the time when "manlike" and "apelike" types diverged, partly because of the fossil record and partly because of trouble in defining "man." Fossil finds are so few and so scattered in time and location that it is difficult to gather adequate and appropriate evidence.
6. With the discovery of *Zinjanthropus*, tool making was extended back to approximately 1,750,000 years ago. Prior to this discovery it was known that tool-using men similar to Java man had lived in Europe, Asia, and Africa between 600,000 and 350,000 years ago.
7. The first animals to which the name "man" is definitely assigned are the pithecanthropines, who existed between 600,000 and 350,000 years ago. Therefore, these dates are frequently taken as indicating how long man has been on the earth. The glacial periods are our most accurate method of dating this time span.
8. *Proconsul* and *Oreopithecus* extend our knowledge of primates back into the late Miocene and early Pliocene ages. Some anthropologists regard *Proconsul* (of Miocene times) as ancestral to the apes, but others insist that it is primitive enough to have come earlier than the divergence of the hominid and ape lines. *Oreopithecus* of late Miocene and early Pliocene has so many humanlike, rather than apelike, features that most authorities classify it as the earliest known representative of the family of man—the Hominidae.
9. The major modern races of man are Negroid, Mongoloid, and Caucasoid. A number of superficial characteristics are used to distinguish members of different races, but these characteristics are highly variable, so much so that anthropologists rely mainly on skull characteristics.
10. Evidence of the use of fire allows us to postulate that man cooked his food, used the fire for warmth, and was thus better able to withstand the cold. The development of improved weapons indicates more efficient hunting. The production of more sophisticated tools indicates greater intelligence and more highly developed technology. Huge piles of animal bones indicate that men hunted and lived in groups. The knowledge of group activity necessitates the use of language for communication. Evidences of pins, needles, and buttons indicate the development of clothing. These and numerous other examples show how we use cultural evidences as "tools" to interpret man's development.
11. Whenever whole skeletons are reconstructed on the basis of a few fossil bones, anthropologists run the risk of erroneous reconstruction. However, they have often reconstructed skeletons from a few critical

bones and later found more complete skeletons that verified their reconstructions. Because certain types of structures are always found together, because basic homologous patterns are similar, and because members of the same genus and to a lesser extent the same family, have certain characteristics in common, reconstruction based upon a few critical parts of the skeleton is often attempted and is frequently successful.

12. Fifty thousand years ago, Cro-Magnon man had essentially the appearance of modern man. The only noticeable difference was that he had a larger skull and was larger in size than most people today. He survived in a land inhabited by wild and savage animals, drew superb pictures of these animals deep within his caves, carved tools and ornaments, and made finely chipped stone points. The fact that he had invented neither automobile nor airplane does not reflect on the Cro-Magnon's intelligence—only on his culture.

REFERENCES

Useful books:

Boule, M., and H. Vallois. 1957. *Fossil Men*. Holt, Rinehart and Winston, New York

Carson, H. 1963. *Heredity and Human Life*. Columbia University Press, New York

Clark, W. LeGros. *The Antecedents of Man: An Introduction to the Evolution of the Primates*: Harper Torchbooks, New York

Hill, W. C. *The Primates: Comparative Anatomy and Taxonomy* (A seven-volume set, of which volumes 1-5 are now available: Vol. I, 1953; Vol. II, 1955; Vol. III, 1957; Vol. IV, 1960; Vol. V, 1962). John Wiley & Sons, New York

Hoagland, H., and R. Burhoe (eds.), 1962. *Evolution and Man's Progress*. Columbia University Press, New York

Korn, N., and H. Smith. 1959. *Human Evolution: Readings in Physical Anthropology*. Holt, Rinehart and Winston, New York

Lasker, G. 1961. *The Evolution of Man*. Holt, Rinehart and Winston, New York

——— 1963. *Human Evolution: Physical Anthropology and the Origin of Man*. Holt, Rinehart and Winston, New York

Tax, S., and A. Kroeber (eds.), 1962. *Anthropology Today: Selections*. University of Chicago Press, Chicago

Tylor, E. 1958. *Primitive Culture*: Vol. I, *The Origins of Culture*. Harper Torchbooks, New York

Articles in journal:

Dobzhansky, T. 1960. "The Present Evolution of Man." *Sci. Am*. 203 [3] 206

Napier, John. 1962. "The Evolution of the Hand." *Sci. Am*. 207 [6] 56

FILMS

Life, Time and Change, Part X: *Evolution of Man*, No. 11, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *Inheritance in Man*, No. 4, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Genetics, Part VI: *The Treasury of Human Genes*, No. 12, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)
Man and His Culture, 1954, (sd, b & w, 15 min), p or r, EBF
The Brotherhood of Man, 1946, (sd, c, 10 min), p or r, Contemporary Films
The Story of Prehistoric Man, 1953, (sd, b & w or c, 11 min), p or r, Coronet

Chapter 38 THE CULTURAL EVOLUTION OF MAN

RATIONALE

This chapter is the last of five specifically concerned with evolution. It completes the discussion of human evolution begun in the previous chapter.

By at least 25,000 years ago, and undoubtedly earlier, man had acquired many of the abilities that make modern life possible. These included the ability to make and use tools, to talk, to transmit knowledge, to work together, to respect wise leadership, and to look into the future toward a better life. Once these abilities were established, human communities of hunting and food-gathering peoples were culturally ready for the change to settled, stable communities of agricultural peoples. The cultivation of plants and the domestication of animals, both of which occurred between 10,000 and 7,000 years ago, made a stable, nonmigratory life possible. With widening knowledge of what to plant and when to plant it, and of how to recognize valuable variations in a crop of plants, man began to improve by artificial selection the wild plants he cultivated. He created field crops beautifully adapted to serve his needs.

With animals, too, artificial selection was used. By raising young animals and retaining those tame enough to keep and breed in captivity, man gradually domesticated the animals of value to him. The transition from nomadic hunter to settled agriculturist probably went through an intermediate step in which villages were located on the banks of waters suitable for fishing.

Man's most valued plants, or most of them, from root crops to grass crops, spread from four major areas of development: (1) tropical Southeastern Asia; (2) temperate Southwestern Asia; (3) subtropical or temperate Mexico and Central America; and (4) the Central Andes of South America.

With the advent of agricultural communities came the first great landowners and, in time, the first great civilization. This great change in man's way of life came about independently of physical changes in the body. Cultural evolution, independent of organic evolution, had developed, with four new features for determining human behavior: (1) cultural inheritance, (2) the ability to alter the environment, (3) learned cooperation, and (4) the ability to look ahead to desired goals.

Cultural evolution depends upon the learning process for the transmission from generation to generation of all that has been learned, invented, and created. The kind of behavior this learning helps produce—man's cultural posture—cannot be transmitted by means of genes.

1. Delicately precisioned stone tools, artistic and informative paintings and engravings on the walls of caves, and carefully constructed graves indicate that prehistoric man had great skill and craftsmanship, the ability to use tools, to talk and to transmit knowledge, and to work together. Unlike modern man, he had not yet learned to control his environment.
2. The chief characteristics of the food-gathering way of life were a nomadic existence in a search for game and edible plants, the cooking of food in open fires or huge pits, and the use of fire to drive game animals into places where they could be captured. Detailed knowledge of plants and animals, together with knowledge of seasonal fluctuations, were a requirement. Food gatherers learned to use every conceivable part of their gathered food in a wide variety of ways much in the same way as the Plains Indians used the buffalo. The nomadic existence probably gave way to one-man rule rather than to prehistoric democracy because with the advent of agriculture, power would lie in the ownership of land. One man could, by marrying his sons and daughters into other landowning families, control more and more land. The heads of large families thus became local rulers, around whom soldiers, priests, tradesmen, artisans, and others came to live.
3. Before settled agricultural life was possible, man had to learn what plants were of most value to him, what kinds of seeds should be saved, and which varieties of plants were best suited to the hazards of agriculture. He had to learn how to clear the land and turn the soil, when to plant (to avoid freezes and droughts), and how to keep destructive animals away from the growing crops. He had to defend his land and crops against marauding tribes, and he had to harvest the crop quickly and store it in edible condition, so that it could be used through the long winter.
4. To be successful in raising seed crops, man had to select those plants that had stiff seed heads and grain that fell out of the hulls easily. His cereal grains indicate that he made this selection very early. The use of Old World cotton for cloth is evidence that primitive man had selected a diploid species of cotton for his purposes. Other evidence indicates the spread of favored plants from specific centers of origin, indicating that man already had selected the plants best adapted to his needs and was taking them with him as he traveled the globe.
5. The rise of agriculture, followed by domestication of animals, made man independent of the abundance or scarcity of game animals and edible wild plants. He no longer needed to keep on the move. Land, as property, became important, so that rules and laws that protected ownership of property were necessary. As permanent settlements grew in size, so man grew in his responsibilities. He could no longer go his own way and do as he pleased, free from criticism or punishment. Cooperation became the accepted way, with division and specialization of labor among the men, and with time devoted to teaching the way of life to each successive generation. Promiscuous living in tribal groups gave way to family living, with rights of property passing from father to son.
6. Several broad insights dominate others. The study of cultural evolution indicates that as populations continue to grow and technologies

continue to advance, an increasing premium is being placed upon: (a) man's ability to learn, (b) his tolerance of more and more crowding from his fellow men, (c) his adaptability to the growing difficulty of "making his mark" as an individual apart from all other people, (d) his stability in the face of increasing governmental regulation of society, and (e) his acceptance of his inability to forestall change—for the world man has made is changing (and has been for hundreds of years) at an ever more rapid rate, far beyond the ability of individuals to control.

7. Nearly all the basic ingredients for today's civilization have been present in human society for thousands of years: (a) the basic selection of crop plants and domestic animals on which all civilization is based (the only changes since prehistoric times have been further improvements, for which the basic pattern was begun long ago); (b) the cultural evolution of teaching and learning, including writing (our modern technology and all our scientific discoveries are based upon nothing more than a continuation of this pattern of education); (c) the evolution of government and of extragovernmental cooperation among men (again, the beginnings were ancient); and other, similar points.
8. Carbon-14 dating has allowed us accurately to place in time tools, utensils, bits of clothing, and other cultural remnants of the last 15,000 years (and more), when man's cultural evolution began to proceed fairly rapidly toward the civilizations of today. By the accurate determination of the sequence in which various types of tools, utensils, and other cultural objects developed, we can trace—as we have—man's progress from nomadic, primitive existence to the first civilizations.

REFERENCES

Useful books:

Durant, Will. 1935. *Story of Civilization*: Vol. I, *Our Oriental Heritage*. Simon and Schuster, New York

Salomon, J. *Prehistory*. Dell Books, New York

Articles in journals:

Adams, R. 1960. "The Origin of Cities." *Sci. Am.* 203 [3] 153

Braidwood, R. 1960. "The Agricultural Revolution." Sci. Am. 203 [3] 130

Butterfield, H. 1960. "The Scientific Revolution." *Sci. Am.* 203 [3] 173

Davis, K. 1963. "Population." *Sci. Am.* 209 [3] 62

Hockett, C. 1960. "The Origin of Speech." *Sci. Am.* 203 [3] 88

Müller-Beck, H. 1961. "Prehistoric Swiss Lake Dwellers." *Sci. Am.* 205 [6] 138

Sahlins, M. 1960. "The Origin of Society." *Sci. Am.* 203 [3] 76

Scrimshaw, N. 1963. "Food." Sci. Am. 209 [3] 72

FILMS

The Hunters, 1959, (sd, b & w or c, 73 min), p or r, Contemporary

Life of a Primitive People (Africa), 1957, (sd, b & w or c, 13½ min), p or r, Coronet

Man and His Culture, 1954, (sd, b & w, 15 min), p or r, EBF

The Story of Prehistoric Man, 1953, (sd, b & w or c, 11 min), p or r, Coronet

Chapter 39 THE LIVING WORLD

RATIONALE

This and the following chapter are organized on a broad ecological basis, dealing with populations of organisms and their relation to the present world biome. Having by now analyzed living organisms on the basis of their chemical and cellular makeup, their development, their unity and diversity, and their hereditary and evolutionary patterns, the students will now investigate organisms and their place in nature today.

The concept of an ecosystem includes all the ways in which individual organisms, and populations of organisms, interact with one another and with their nonliving environment. The ecosystem includes not only all the organisms of a given area but their energy sources, their supplies of necessary elements, provisions for cycling elements between the living and nonliving parts of the environment, and suitable climates.

Organisms have adapted to a wide variety of habitats, and this chapter outlines four general types of habitats in the world. These are: (1) oceans, (2) forests, (3) grasslands, and (4) deserts. For each of these the students should be able to draw upon their knowledge of plants and animals gained earlier in the course to illuminate specific features of the individual types of ecosystems. From this chapter the students should gain at least a rudimentary comprehension of the tremendous variety of habitats populated by the earth's organisms. They should also appreciate the significance of the relatively stable environment of the oceans compared with the many and changing environments of the land. Adaptation to the various environments can be traced to genetic variability and natural selection, which have perfected organisms for almost every conceivable environment on the face of the globe.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 706)

1. The conditions necessary for an ecosystem are : (a) an energy source, and organisms that are able to use it; (b) a supply of the elements required by the organisms of the ecosystem; (c) mechanisms (requiring specific kinds of organisms) for cycling the elements between the living and the nonliving parts of the environment; and (d) suitable climatic conditions.
2. The primary producers in the sea—the diatoms, the dinoflagellates, and some seaweeds—are dependent on light in order to carry on photosynthesis. These photosynthetic plants are the basis for all life in the sea; without these algae to feed upon, the consumers could not survive, and the seas would become sterile.
3. A cloudy day would reduce the photosynthetic output of plant plankton because it would reduce the amount of light available for photosynthesis. The wind would produce no effect.
4. The food webs in the surface waters of the open sea and on land are similar in that both rely on autotrophic organisms as a primary food source. Herbivorous animals, the primary consumers, prey upon the plants and in turn are preyed upon by carnivores, the secondary consumers. When the animals and plants die, decomposers return their

elements to the environment, where these elements can be utilized again by other living organisms.

5. As both the ocean depths and a cave on land lack light, no primary producers can be present. Therefore, the organisms that live in either the depths of the ocean or in a cave depend on food that has filtered in or been brought from other environments.
6. Life in the ocean depths can be maintained only if sufficient food drifts down from the upper layers and if a supply of dissolved oxygen is available to the organisms inhabiting the depths. The temperature and the humidity of the ocean depths are very stable.
7. Life in the oceans near the shore is affected by many factors. Rivers bring in fresh water and also organic and inorganic materials; and a variety of habitats, such as rocks, pilings, mud, or sand, are available to organisms. Life near the shore is subjected to fairly great environmental extremes—the rise and fall of the tides, changes in water and air temperature, and changes in salinity.
8. Environmental conditions that are more stable in the ocean than on land include temperature, humidity, and the supply of inorganic substances (except in the deep waters of some isolated seas). The tropical rain forest is the land environment which most nearly approaches the stability of the seas.
9. While all marine organisms are supported by water, terrestrial plants and animals have had to develop suitable supporting structures. Moreover, land organisms must be able to conserve water and adapt to widely varying climatic and physical conditions that prevail on land but not in the ocean's waters.
10. Terrestrial plants and animals usually conserve water by means of a waterproof (or almost waterproof) covering that keeps water inside the body. In addition, respiratory surfaces, such as lungs in chordates and air spaces behind plant stomata, are internal in order to reduce evaporation. Some plants can absorb water after rains and store it for many months, and some animals can derive most of their water from the foods they eat (and also lose little water in their urine).
11. A forest community is characterized by adequate rainfall and a relatively uniform environment, including shade and protection from the winds, high humidity (due to evaporation of water from the trees), a great variety of habitats, and suitable cover. Tropical rain forests are the most uniform of terrestrial environments. Grassland communities, as opposed to forests, are communities of greater stress. They have moderate amounts of rain, but are often subject to drought. They tend to be dry, exposed to environmental extremes of temperature, humidity, and wind. They present a relatively uniform and small number of habitats, and offer little cover for animals; the type of community that prevails depends upon the most unfavorable conditions of the dry years. A desert community lacks a rich mat of vegetation because of the dearth of water. The environmental stress is much greater than in grasslands. Deserts are characterized by low humidity, lack of protection against winds, and extreme temperature fluctuations. Relatively little cover and environmental protection is offered desert organisms.
12. A tropical rain forest has almost uniform conditions of water and temperature. Its great variety of species of plants are always green. Deciduous forests, on the other hand, are exposed to greater environmental extremes, and their trees are dormant through the winter. A deciduous

forest consists of relatively few species of trees and does not provide the richness of variety of either plant or animal life found in a tropical rain forest.

13. The main factors accounting for the richness and diversity of tropical life are the relatively high, even temperatures and the abundance of water. The tropics have had a stable environment for a very long time; the four glaciers of the Pleistocene did not affect these areas. Next to marine environments, the environment of a tropical rain forest is the most stable known; certainly it is the most stable land environment.

REFERENCES

Useful books:

Chapman, V. 1960. *Salt Marshes and Salt Deserts of the World.* John Wiley & Sons, New York

Dietrich, G., and F. Ostapoff. 1963. *General Oceanography.* John Wiley & Sons, New York

Hill, M. *The Sea*: Vol. I, 1962; Vol. II, 1963; Vol. III, in preparation. John Wiley & Sons, New York

Kendeigh, S. 1961. *Animal Ecology.* Prentice-Hall, Englewood Cliffs (N.J.)

Klopfer, P. 1962. *Behavioral Aspects of Ecology.* Prentice-Hall, Englewood Cliffs (N.J.)

Mayer, W., and R. van Gelder. 1963. *Physiological Mammalogy*: Vol. I, *Mammalian Populations.* Academic Press, New York

Odum, E. 1963. *Ecology.* Holt, Rinehart and Winston, New York

Reid, G. 1961. *Ecology of Inland Waters and Estuaries.* Reinhold, New York

FILMS

The Grasslands, 1962, (sd, b & w or c, 17 min), p or r, EBF

The Temperate Deciduous Forest, 1962, (sd, b & w or c, 17 min), p or r, EBF

The Desert, 1962, (sd, b & w or c, 22 min), p or r, EBF

The Community, 1962, (sd, b & w or c, 11 min), p or r, EBF

The High Arctic Biome, 1960, (sd, b & w or c, 22 min), p or r, EBF

The Cave Community, 1961, (sd, b & w or c, 13 min), p or r, EBF

What is Ecology? 1962, (sd, b & w or c, 11 min), p or r, EBF

The Sea, 1962, (sd, b & w or c, 26 min), p or r, EBF

Ecology, Part IX: *Plant and Animal Distribution*, No. 1, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *Marine Ecology*, No. 6, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *Tundra Ecology*, No. 7, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *The Deciduous Forest*, No. 8, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part XI: *The Tropical Rain Forest*, No. 9, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *Grasslands and the Desert*, No. 10, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 40 MAN AND THE BALANCE OF NATURE

RATIONALE

Chapter 39 introduced the concept of the ecosystem with its interrelations of organisms and their physical environment. This chapter concentrates on man and his particular relationship to the living world; it might be called a chapter on human ecology. It points out that man, who has the power to alter his environment, has in some cases altered it wisely and in many cases altered it unwisely. In some measure this is a chapter on conservation, exhorting man to use his environment for the benefit of present and future generations.

The emphasis on the first part of the chapter is on man himself, including his triumphs over predators and infectious diseases and his efforts to provide adequate food supplies for all people. The problem of unequal food distribution remains to be solved.

With the continued growth of the world's human population, the need for more food, especially protein, becomes an increasingly urgent problem. In addition to requiring adequate food supplies, man also requires adequate supplies of fresh water. Unfortunately, at the same time that he uses more and more water, he is also polluting more and more of his limited supply.

While the earth's nonrenewable resources, such as coal and oil, must be used wisely to prevent their early exhaustion, its living resources are constantly renewable. But they, too, require very careful management, for man has already been responsible for the extinction of a number of animal species and for the vanishing of many plants from their natural habitats. Man has an obligation to so manage his living world that he leaves a heritage of food, clean water, and an unravaged environment for future generations.

ANSWERS TO GUIDE QUESTIONS AND PROBLEMS (text page 719)

1. With traps, guns, and poisons, man eliminates the larger predatory animals in his vicinity. Similarly, he hunts—for food, for clothing, and for pleasure—the large game animals in his immediate environment. He alters the environment by draining swamps, cutting forests, plowing grasslands, and fencing farms. All of these human activities drastically reduce the supporting environment for, and thus the numbers of, large animals other than man.
2. By largely eliminating natural selection as a factor in his own life, man has become a force affecting his own evolution. No longer has he found it necessary to adapt completely to his environment; he adapts the environment to himself.
3. Vegetable diets are frequently inadequate because plant proteins do not contain sufficient amounts of the ten amino acids essential to life. Unless very large quantities of certain types of plant foods are eaten, individuals will suffer a protein deficiency.
4. As the world population increases, we are faced with the problem of increasing food production sufficiently just to feed the population, not to speak of improving the standard of living. Much of the land is neces-

sarily nonproductive because it is under ice, or too steep, or too stony, or has too little fertile soil. Essentially all the suitable land is now being worked. Man must develop better methods of farming, better crops, and better animals if we are to have enough food and an adequate diet. Even today, animal protein is in short supply. The sea is potentially man's greatest hope; water covers over half the land and abounds with fish, an excellent source of protein. Sooner or later, however, the primary problem will have to be faced—how to win some measure of control over the numbers of humans on the earth.

5. Forests provide a most efficient trap for rain. They protect the soil from erosion and allow the land to continue to trap and dole out the water man needs. As forests are cut down, the soil is eroded, and water runs off rapidly, producing floods and mud-laden, polluted streams and rivers. Underground water supplies diminish and rivers shrink. The conservation of forests is necessary if we are to maintain an adequate supply of usable fresh water.
6. The establishment of national parks and wildlife areas preserves forests and marshes and provides a sanctuary for wildlife. Many animals and plants that might otherwise become greatly reduced in numbers, or even extinct, are preserved for future generations. The trees themselves control erosion and maintain a supply of fresh water. The recreational value of these areas cannot be overestimated for ourselves or our descendants.

REFERENCES

Useful books:

Bennett, G. 1962. *Management of Artificial Lakes and Ponds*. Reinhold, New York

Crampton, E., and L. Lloyd. 1960. *Fundamentals of Nutrition*. W. H. Freeman, San Francisco

Gainey, P., and T. Lord. 1952. *Microbiology of Water and Sewage*. Prentice-Hall, Englewood Cliffs (N.J.)

Hanson, H., and E. Churchill. *The Plant Community*. Reinhold, New York

Malthus, T. *On Population*. Modern Library, New York

Munves, E., and H. Fleck. *Everybody's Book of Modern Diet and Nutrition*. Dell Books, New York

Sauvy, A., and J. Lenica. *Population Explosion*. Dell Books, New York

Schery, R. 1952. *Plants for Man*. Prentice-Hall, Englewood Cliffs (N.J.)

Sears, P. *Where There is Life*. Dell Books, New York

Articles in journals:

Deevey, E. S. 1960. "The Human Population." *Sci. Am.* 203 [3] 194

McDermott, W. 1961. "Air Pollution and Public Health." *Sci. Am.* 205 [4] 49

FILMS

Ecology, Part IX: *Applied Ecology*, No. 12, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *Energy Relations*, No. 3, 1962, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Ecology, Part IX: *Limiting Factors*, No. 4, 1963, (sd, c, 28 min), p or r, AIBS (McGraw-Hill)

Chapter 41 A PERSPECTIVE OF BIOLOGY

RATIONALE

This chapter provides a fitting summary of the information, hypotheses, and theories of biology. It is an attempt to help students review the impact of this course in the light of their future roles as adult citizens—as part of an intelligent populace that is not scientifically ignorant. The chapter is in a sense a candid admission that students will not remember a welter of detail. But they can take away with them a way of thought, a way of looking at things, a way of understanding the living world.

In addition to providing a brief summary of the salient features of the living world, the concluding comments pose a challenge for man, who alone of all living organisms, possesses the ability to control the way in which he exists as a part of the living world. Intelligent control demands knowledge. Biology, properly presented, should provide much of the knowledge necessary for intelligent planning for the future of life on this planet.

In view of the nature of this final chapter, it would be presumptuous to provide suggested questions, bibliographies, and films. Instead, the four pages of text provide the teacher with the opportunity to demonstrate that students can leave the course with inquiring minds—minds capable of thinking in intelligent terms about the problems of life on the earth.

APPENDIX

FILM LISTINGS

Abbreviations used in film listings:
sd = sound   b & w = black and white   min = minutes
si = silent   c = color
p = purchase   r = rental

This *Teacher's Manual* lists films that may prove useful to the teacher in elucidating points that are particularly difficult or that require, for accurate interpretation, a sequence of visual impressions. Where, in many cases, the entire film may be applicable, in some cases the teacher may wish to use only small segments of it applicable to the particular textual point to be illustrated. Each film should be judged in relation to the particular class and the needs of the lesson. Many more films have been cited than can be used; a well-integrated selection of them can be assured only by teacher preview.

The films cited as appropriate for certain chapters of the text are keyed by the abbreviations in the following list to the film producers or distributors named in association with the abbreviations. As most school systems support an audio-visual center and wish requests for films routed to the centers, these addresses will be useful primarily to your immediate film supplier. If your audio-visual center does not already have the listed films available for use in your area, you may wish to indicate those that should be a part of the center because of their continued and valuable use. The *Teachers' Handbook* discusses films in greater detail than is possible here.

FILM PRODUCERS AND MAJOR DISTRIBUTORS

AIBS – McGraw-Hill
Text Film Division, McGraw-Hill Book Co., Inc. 330 W. 42 St., New York 36, N. Y.

ASM
American Society of Microbiologists, Committee on Visual Aids, School of Medicine, University of Pennsylvania, Philadelphia 4, Pennsylvania

Bajer
Dr. A. Bajer, Plant Physiology Laboratory, Jagellonian Institute, Cracow Poland

Bray
Bray Studios, 729 7th Ave., New York 19, N. Y.

Carnegie
Carnegie Institution of Washington, 1530 P. Street, N.W., Washington 5, D. C.

Carousel
Carousel Films, Inc., 1501 Broadway, New York 36, N.Y.

Contemporary
Contemporary Films, 267 W. 25 St., New York 1, N. Y.

Dowling
Pat Dowling Productions, 1056 S. Robertson Blvd., Los Angeles 35, California

EBF

Encyclopaedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Illinois

Handel

Handel Film Corporation, 6926 Melrose Ave., Hollywood 38, California

IFB

International Film Bureau, 332 S. Michigan Ave., Chicago 4, Illinois

Indiana

Audio-Visual Center; Indiana University, Bloomington, Indiana

MLA

Modern Learning Aids, 160 E. Grand Ave., Chicago 11, Illinois

Nebraska

University of Nebraska, Bureau of Audio-Visual Instruction, Extension Division, Lincoln 8, Nebraska

Phase

Arthur T. Brice, Phase Films, 656 Austin Ave., Sonoma, California

Roberts Rugh

Dr. Roberts Rugh, c/o Columbia Medical Center, 630 W. 168 St., New York 32, N. Y.

Sterling

Sterling Educational Films, 6 E. 39th St., New York 16, N. Y.

UW

United World Films, Inc., 1445 Park Ave., New York 29, N. Y.

S.C.E.R.T., West Bengal
Library
Calcutta
25/3

372.3
NCE